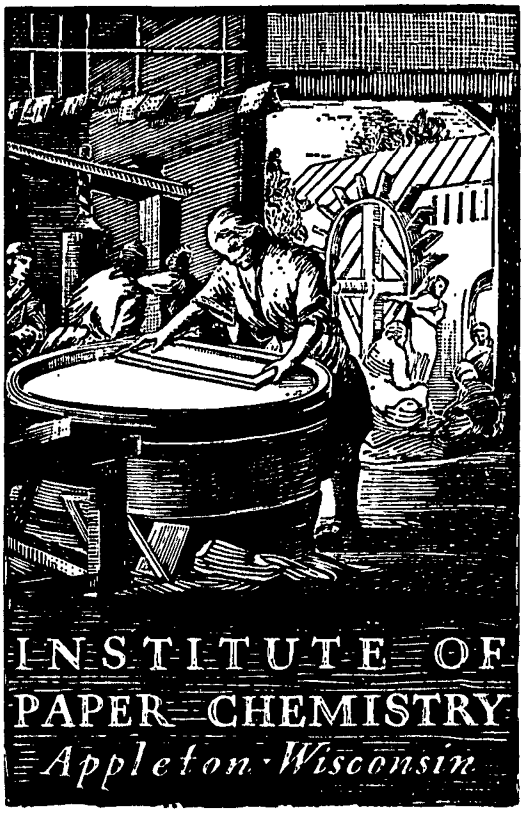

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Nine
A Progress Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

August 31, 1977

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Appleton, Wisconsin

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SUMMARY

Shagbark hickory has a wood specific gravity of 0.65 and an average bark specific gravity of 0.72. Bark extractives levels average 14.6%. Morphologically, the bark contains a large amount of fiber, some sieve tubes but little or no sclereids. Pulping shagbark hickory bark gave a solids yield of 28.3%. Screening the bark pulp resulted in 15 grams of fiber being produced for every 100 grams of bark pulped. This is the highest percentage of fiber produced from bark of any of the species examined except white ash. Mechanical treatments to separate and segregate wood/bark chip mixtures were not successful with this species. Hammermilling resulted in only an 11% bark removal with a 4% wood loss. Water flotation would not work either as both wood and bark tend to sink at low moisture contents.

Post oak, based upon values in the literature and measurement data obtained from trees sampled as part of the project, has an average wood specific gravity of 0.64 and a bark specific gravity of 0.56. Extractives levels for wood and bark were 4.3 and 8.2%, respectively. Pulping post oak bark produced a solids yield of approximately 46%. Screening the bark resulted in 4 grams of fiber being produced for every 100 grams of bark pulped. Hammermilling gave good results with a 47% bark removal and a 6% wood loss. Compression debarking also gave promising results and a useful approach might be a "screening-compression debarking or hammermilling-rescreening" procedure. Water flotation segregation procedures are not feasible with this species as wood and bark have similar densities at low moisture contents and both sink at higher moisture contents.

Pin oak was found to have a wood specific gravity of 0.61 and a bark specific gravity of 0.71. Extractives levels were 4.4 and 14.9%, respectively, for the wood and the bark. The bark, when pulped, had a solids yield of approximately 26%. Screening the pulp resulted in 2% usable fiber being produced. Hammermilling gave intermediate results with this species with 33% bark removed and a 6% wood loss when material on the 14-mesh screen was retained. A useful approach with this species also might be screening, hammermilling the fractions high in bark and rescreening. Segregation through water flotation does not appear possible with this species as the wood and bark are too similar in density at the various moisture contents.

Black oak has a wood specific gravity of 0.57 and a bark specific gravity of 0.68. Extractives levels were 5.0 and 15.4%, respectively, for the wood and the bark. Morphologically, the bark contains mostly fiber in the usable fraction. Pulping black oak bark gave a solids yield of approximately 31%. Screening the pulp resulted in 5% phloem fibers remaining on the 60- and 100-mesh screens. Hammermilling resulted in a 37% reduction in bark levels and a 7% wood loss but a useful approach might be to make a quick segregation by screening, hammermilling the fractions high in bark and rescreening. Water flotation segregation is not a feasible technique for this species as the densities of wood and bark are too close at low moisture contents and both would sink at higher moisture contents.

A wood specific gravity of 0.60 and a bark specific gravity of 0.67 were determined as average values for American beech. Extractives levels of 1.5 and 10.6% were found to be appropriate for the wood and bark of this species. Pulping American beech gave a solids yield of 37% but, when screened, 93% of the solids passed through the 200-mesh screen. The result was usable fiber of only 0.25%

and sieve tubes remaining of 0.35%. Consequently, it appears the use of whole-tree chips of American beech wouldn't have much effect on the pulp. Hammermilling has some merit with this species with a 43% reduction in bark levels and a 6% wood loss by retaining material on the 14-mesh screen. Water flotation has some possibility but only when the wood/bark chip mixture is drier than normal (30% or less moisture content).

Added again in this report is a section giving the Btu's, ash, calcium and silica levels for all 37 species investigated thus far. Other added features include a dwell-time study and a table giving the modulus of elasticity for all species investigated.

INTRODUCTION

Progress Report Eight completed the bark characterization research for the agreed-upon total of 32 pulpwood species. However, a questionnaire to interested companies indicated there was sufficient interest to warrant characterizing the bark of an additional ten species. Shagbark hickory, post oak, pin oak, black oak, American beech, red maple, green ash, black willow, eastern hemlock and eastern white pine were the ten species of greatest interest to the responding companies. The report that follows describes the characteristics of the first five species listed. Progress Report Ten, which is expected to be completed in late December, will characterize the remaining five species. The final report will summarize the results of all species investigated and emphasize the interrelationships that exist between bark morphology, bark strength and alternative methods of making best use of the industry's bark resource. As discussed in the Introduction of Progress Report Eight, changes in the wood raw material supply situation (shortages in 1974 and excess supply in 1976 and 1977), the "dirt" problem associated with whole-tree harvesting, environmental pressure requiring closed pulping systems, and the energy crisis made it necessary to view the bark problem from an entirely new perspective.

Energy and fibrous raw material requirements appear to be key factors in the present wood/bark segregation picture. Delivery of the finished product to the consumer at the lowest energy output requires consideration of harvesting, transporting, chipping, pulping, cleaning, beating, chemical recovery, equipment wear and converting energy costs. Bark has a considerable fuel value if handled by a dry process and appropriate consideration must also be given to energy independence.

There is considerable evidence that, like it or not, use of whole-tree chips will be required to meet future paper and board requirements. To effectively use such material with a minimum distruption in production and a minimum loss in product quality requires continued research on how to handle the "bark" and the associated "dirt" problem. The objective of this report and earlier reports has been to better define the bark problem so alternative methods can be considered and the most appropriate procedure developed for specific mill and raw material situations.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

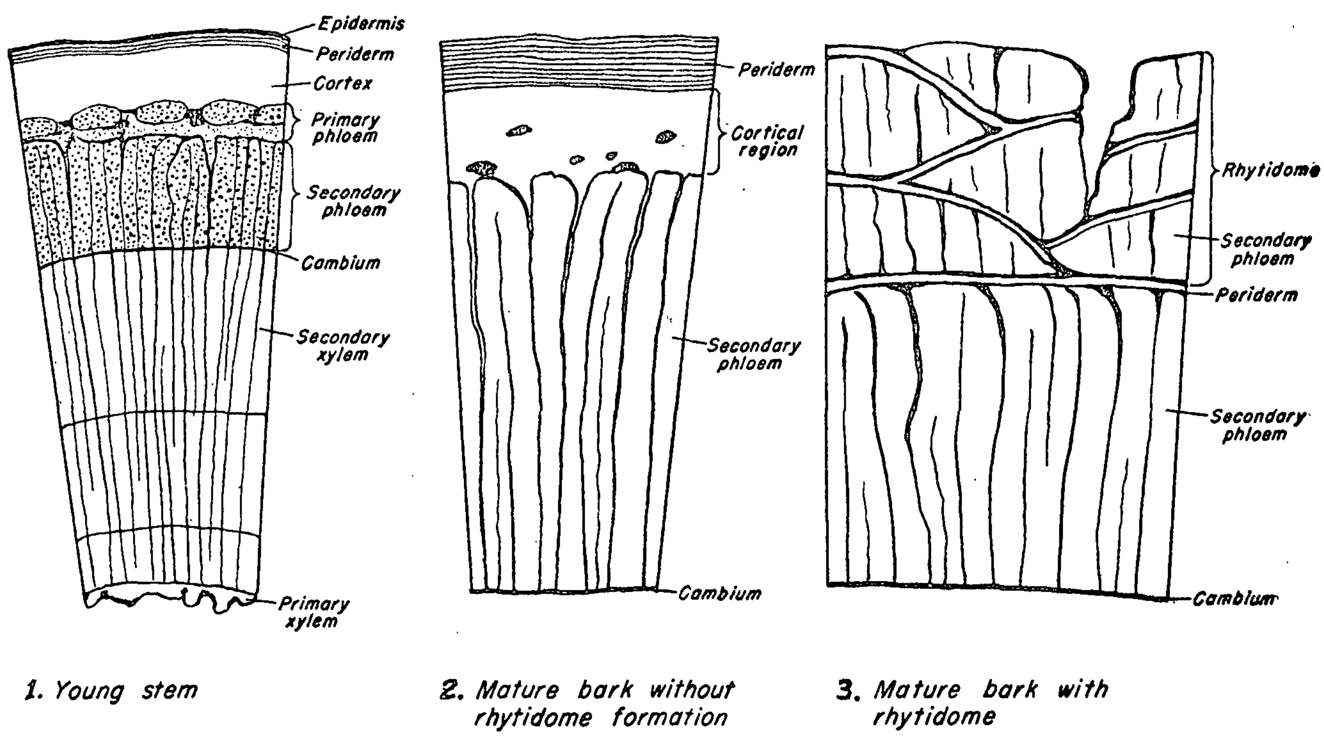


Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, Such as That in the Middle-aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later anatomical examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(\underline{c}\cdot\underline{d})/[\underline{c}-(\underline{b}-\underline{a})]$ where:

$\underline{a}$ = weight of pycnometer + heptane

$\underline{b}$ = weight of pycnometer + heptane + chip

$\underline{c}$ = weight of chip (wet — before being placed in heptane)

$\underline{d}$ = density of heptane.

BARK AND WOOD PROPERTIES OF SHAGBARK HICKORY
[*Carya ovata* (Mill.) K. Koch]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Shagbark hickory grows on varying sites and elevations in almost every state in the eastern half of the United States. With the exception of Florida and the lower coastal plains of the Southeast, the range extends from southern Maine westward to southeastern Minnesota, through most of Iowa to southeastern Nebraska and southward to eastern Texas. Widely distributed in the humid climate of the eastern United States, shagbark hickory is found on upland slopes at elevations of 2,000 ft. in the north, on deep moist soils of alluvial origin and the north and east slopes of fertile uplands further south, and on river bottom lands of Arkansas, Mississippi and Louisiana. Generally slow-growing, shagbark is one of the fastest growing hickories reaching heights of 130-140 ft and diameters of 36 to 48 inches, depending on the site. Having a reputation for long life, this species is moderately tolerant, highly competitive, and reproduces readily from seed, sprouts and root suckers.

WOOD AND BARK MORPHOLOGY

Wood

Shagbark hickory is a hard, strong, high-density wood with a specific gravity of 0.56-0.66 green, 0.62-0.78 ovendry. Growth rings are distinct as are the whitish to pale brown sapwood and the brown to reddish-brown heartwood. It is a ring porous wood with large earlywood pores and an abrupt transition to latewood. Latewood pores are small, solitary and in multiples of 2-3. Parenchyma are conspicuous with a hand lens in fine, continuous, tangential lines which are arranged irrespective of the pores. Rays, 1-5 seriate and homogeneous to heterogeneous, are indistinct to the naked eye. Vessels number 2-11 per sq. mm. Averaging 0.47 mm in length, the largest earlywood vessels are 160-320 µm in diameter. Fibers, thin to thick walled and frequently gelatinous, are 12-20 µm in diameter and average 1.34 mm in length.

Bark

Bark of young shagbark hickory trees is smooth, gray and very hard. As the tree ages, the bark breaks up into wide plates that curl at the ends, giving the characteristically shaggy appearance. The outer bark, for the three trees examined, averaged 57% on a weight basis, with a range from 46 to 66%. Figure 2 illustrates a cross section of shagbark hickory wood and bark. Figure 3, at higher magnification, shows the gelatinous nature of the phloem fibers. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

The inner bark (secondary phloem) of shagbark hickory is characterized by alternate, wavy, tangential layers or bands of gelatinous fibers and phloem parenchyma cells, compactly arranged. The sieve tubes present are conspicuous, usually solitary (sometimes in groups of 2 to 5) and are fairly uniformly distributed throughout the alternate tangential bands of phloem fibers and parenchyma cells. Phloem rays are fairly numerous, 1-5 seriate, up to 25 or more cells high and evenly distributed throughout the inner bark.

The sieve tubes are oval to polygonal in cross section and those cells located near the cambium zone average 75 µm in diameter. The sieve tubes become more or less crushed in the outer regions of the secondary phloem. Examination of the macerated bark of hickory in Project 2929 indicated the sieve tubes to be approximately 0.6 to 0.7 mm in length. The phloem parenchyma cells, arranged in tangential bands, one to three cells in width, are round to oval in cross section and average approximately 30 µm in diameter. Parenchyma cells in a strand often contain solitary crystals.

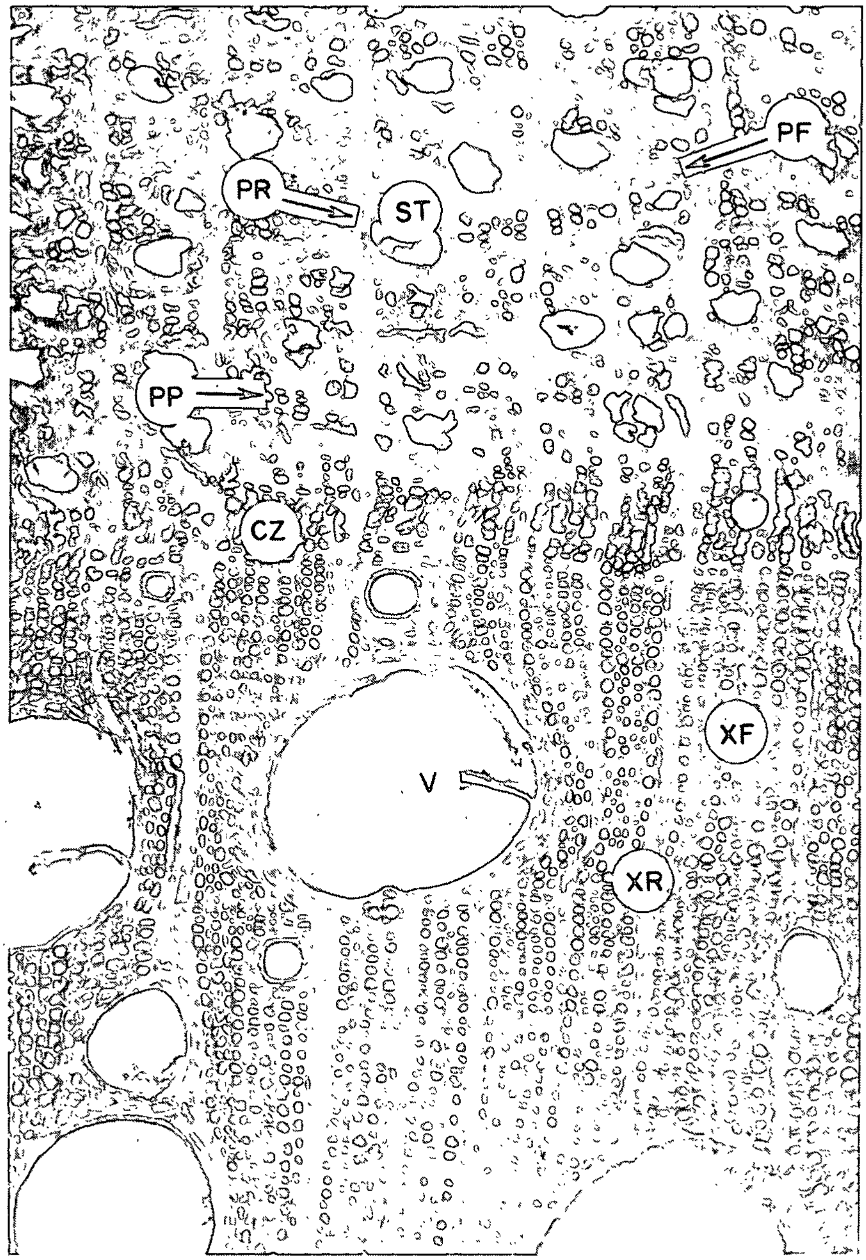


Figure 2. Cross Section of Shagbark Hickory. Illustrated Are a Number of Important Morphological Characteristics Including: Earlywood Xylem Vessels (V), Xylem Rays (XR), Xylem Fibers (XF), Active Cambium Zone (CZ), Thick-walled Gelatinous Phloem Fibers (PF), Phloem Rays (PR), Phloem Parenchyma (PP) and Scattered Large Diameter Phloem Sieve Tubes (ST). Magnification — 120X

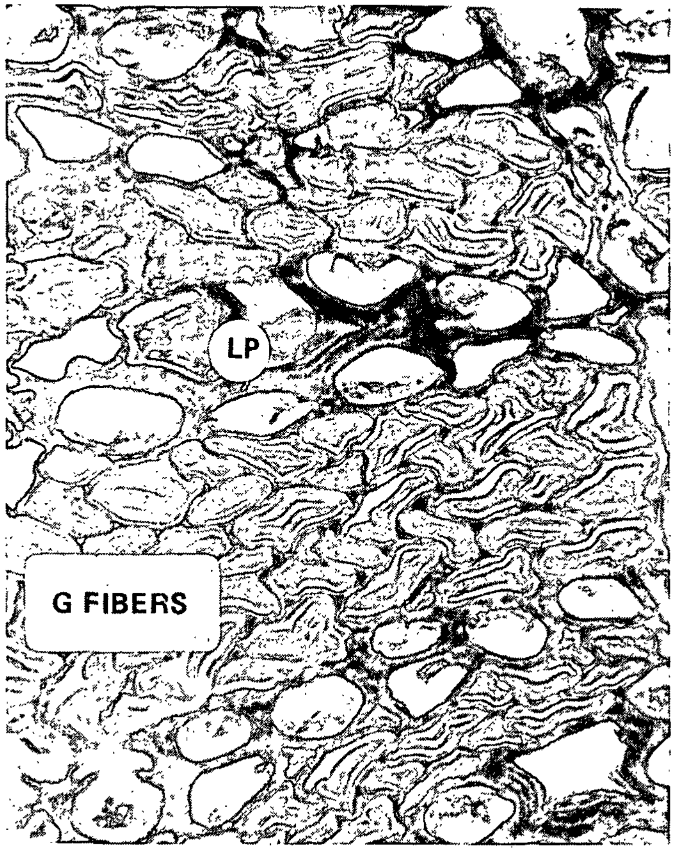


Figure 3. Illustrated Is the Gelatinous Nature of the Phloem Fibers. Magnification — 750X. LP = Longitudinal Parenchyma

The outstanding features of the inner bark of hickory are the large numbers of thick-walled gelatinous fibers and the absence of sclereids. The phloem fibers are aligned in narrow, wavy, tangential bands, 3 to 4 fibers in width. The cross section of the fibers is polygonal in shape and averages approximately 20 μm in diameter. Cell walls of the fiber cross sections appear to be separated into two distinct layers. The fibers could be expected to contribute in a major way to the strength of the inner bark in view of their wavy arrangement.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table I summarizes the information available on wood and bark of shagbark hickory. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of shagbark hickory at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.61 appears appropriate for the wood of shagbark hickory. Our samples were divided into sapwood and heartwood and, in one case, into exterior and interior wood. For 3212-124, the interior wood constituted the first 19 rings out of a total of 45 rings. Our limited data showed the sapwood to be slightly higher in specific gravity than the heartwood. The exterior wood for 3212-124 was also higher in specific gravity than the interior wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

TABLE I

SHAGBARK HICKORY SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.65				Taylor (3)
0.62 (true hickory)			0.52	Manwiller (4)
0.64 (cores)				Maeglin (5)
0.68				Bendtsen and Ethington (6)
0.64				IUFRO (7)
0.64 (sapwood) 0.62 (heartwood)	0.78	0.90	0.84	IPC 3212-121
0.70 (sapwood) 0.67 (heartwood)	0.63	0.80	0.77	IPC 3212-122
0.71 (exterior) 0.67 (interior)	0.65	0.74	0.74	IPC 3212-124

The specific gravity of the total (inner + outer) bark of shagbark hickory is somewhat higher than that of the wood. The outer bark was higher in specific gravity than the inner bark on two of the three trees examined in this project. Overall values suggested for use in species comparisons are 0.65 for wood and 0.69, 0.81 and 0.72 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of shagbark hickory wood. Table II summarizes existing data and includes the three IPC trees examined. Shagbark hickory wood is low in extractives and a level of 3.2% is suggested for use in between-species comparisons. Extractives work done on shagbark hickory bark in this project showed an average level of 14.6%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE II

SHAGBARK HICKORY EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	3.4	Keller, _et al_. (_8_)
Wood	2.8	IPC 3212-122
Wood	2.5	IPC 3212-124
Wood	4.3	IPC 3212-121
Bark	17.2	IPC 3212-121
Bark	11.3	IPC 3212-122
Bark	15.4	IPC 3212-124

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped shagbark hickory bark.

The short, thin-walled sieve tubes (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, there are few, if any, sclereids in the bark of shagbark hickory.

As a check on pulp yield and the nature of the material produced from shagbark hickory, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation. Micropulping shagbark hickory bark resulted in a yield of 27 to 29% solids. When screened, the coarse screens (60 and 100 mesh) retained mostly phloem fibers. The on 150-mesh screen contained many phloem fibers along with sieve tubes and parenchymatous cells. The on 200-mesh and through 200-mesh screens had large amounts of parenchymatous and thin-walled peridermal cells and some phloem fibers and sieve tubes. Figure 4 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 28 grams of solids will result. Of this 28 grams, about 15.1 grams (15.1%) of phloem fibers and 0.1 gram (0.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was higher than for any other hardwood species characterized except white ash. Average arithmetic length of the bark fibers was 1.30 mm, compared to a wood fiber length of 1.28 mm as reported by Taylor (3). Both measurements are on whole fibers, selected in an unbiased manner.

Shagbark hickory chips, containing 19% bark, were pulped to several yields by Keller, et al. (8). They found the yield per cord of rough wood to be greater than it would be using wood alone. However, there was some loss in strength and chemical costs were increased. The pulps were converted to bond paper which was satisfactory except for low opacity and corrugated board of adequate strength.

TABLE III

SHAGBARK HICKORY MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-122	Sample No. 3212-124	Remarks[a]
Yield, % solids	29.3	27.3	
Fraction			
On 60 mesh, %	42.5	54.3	The fraction contained almost 100% phloem fibers with a trace of sieve tubes and parenchymatous cells. Average arithmetic length of the phloem fibers was 1.30 mm
On 100 mesh, %	6.0	4.4	The fraction contained a large percentage of phloem fibers (85-95%) with a small percentage of sieve tubes (<10%) and parenchymatous cells (<5%)
On 150 mesh, %	1.4	1.8	The fraction contained a large percentage of phloem fibers (60-70%) with smaller percentages of sieve tubes (25-35%) and parenchymatous cells (5-15%)
On 200 mesh, %	0.3	0.5	The fraction contained a large percentage of phloem fiber (50-60%) and smaller percentages of sieve tubes (20-30%), and parenchymatous cells (15-25%)
Through 200 mesh, %	49.8	39.0	The fraction contained 100% parenchymatous and thin-walled peridermal cells

[a]Percentages given are on a dry weight basis.

Shagbark hickory bark was also evaluated as a papermaking fiber by Vizvary (9). He found that the inclusion of up to 26% bark in pulp resulted in handsheet strength properties that were comparable to those of handsheets made from wood only. He also found that the effect which bark has on handsheet properties is a function of the degree of refining of the bark fibers as bark fibers are more rapidly degraded by refining than wood fibers.

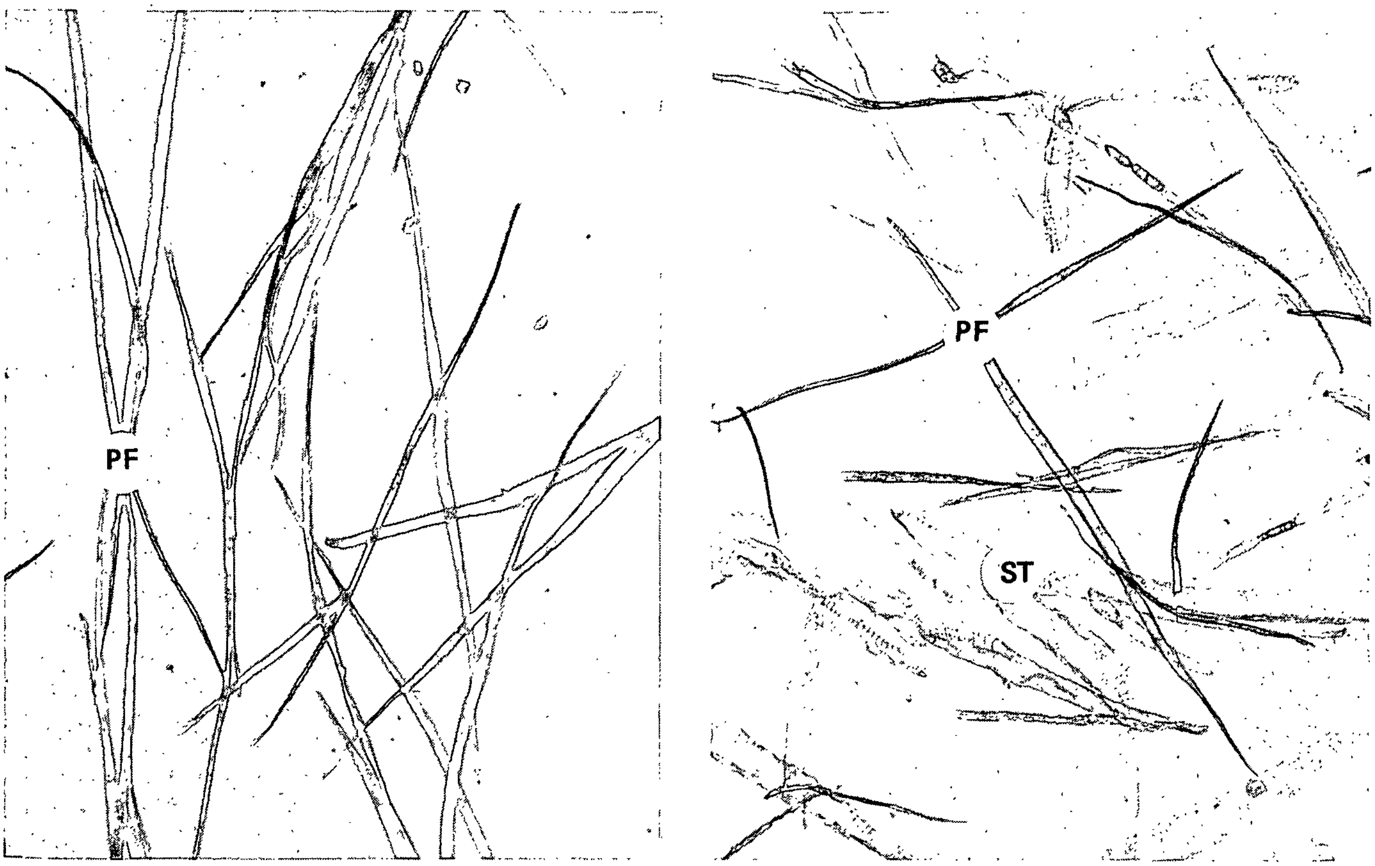


Figure 4. The 60-Mesh Screen (Left) Contained by Weight Almost 100% Phloem Fibers. The 150-Mesh Screen (Right) Contained a Large Percentage of Phloem Fibers (60-70%) with a Small Percentage of Sieve Tubes (25-35%). Magnification — 75X. Symbols Illustrate Phloem Fibers (PF) and Sieve Tubes (ST)

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Wood/bark adhesion in shagbark hickory was studied extensively in Project 2929 (Progress Report Three) and the work was not repeated but a summary of the results of earlier investigations follows.

Dormant season samples collected in March, April, and August revealed a cambium zone 4-5 cells in width and, when adhesion tests were made, failure quite consistently occurred in the inner bark between the last-formed phloem fibers and the phloem parenchyma cells located immediately adjacent to the cambium zone. Observations made on dormant season cross sections indicate the primary zones of weakness in hickory are the undifferentiated cells of the cambium zone and the nonlignified, partially mature phloem parenchyma and sieve tubes just outside the cambium.

During the growing season, wood/bark adhesion decreased and failure occurred either in the cambium zone or in the zone of newly-formed immature xylem cells just outside the cambium. Figure 5 illustrates the changes in location of the zone of failure and Appendix Table XXXVII gives the magnitude of wood/bark adhesion values involved. Adhesion values for shagbark hickory averaged 3.8 kg/cm^2 during the peeling season and 30.6 kg/cm^2 during the dormant season. The dormant season value is higher than that obtained for any species studied thus far.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high

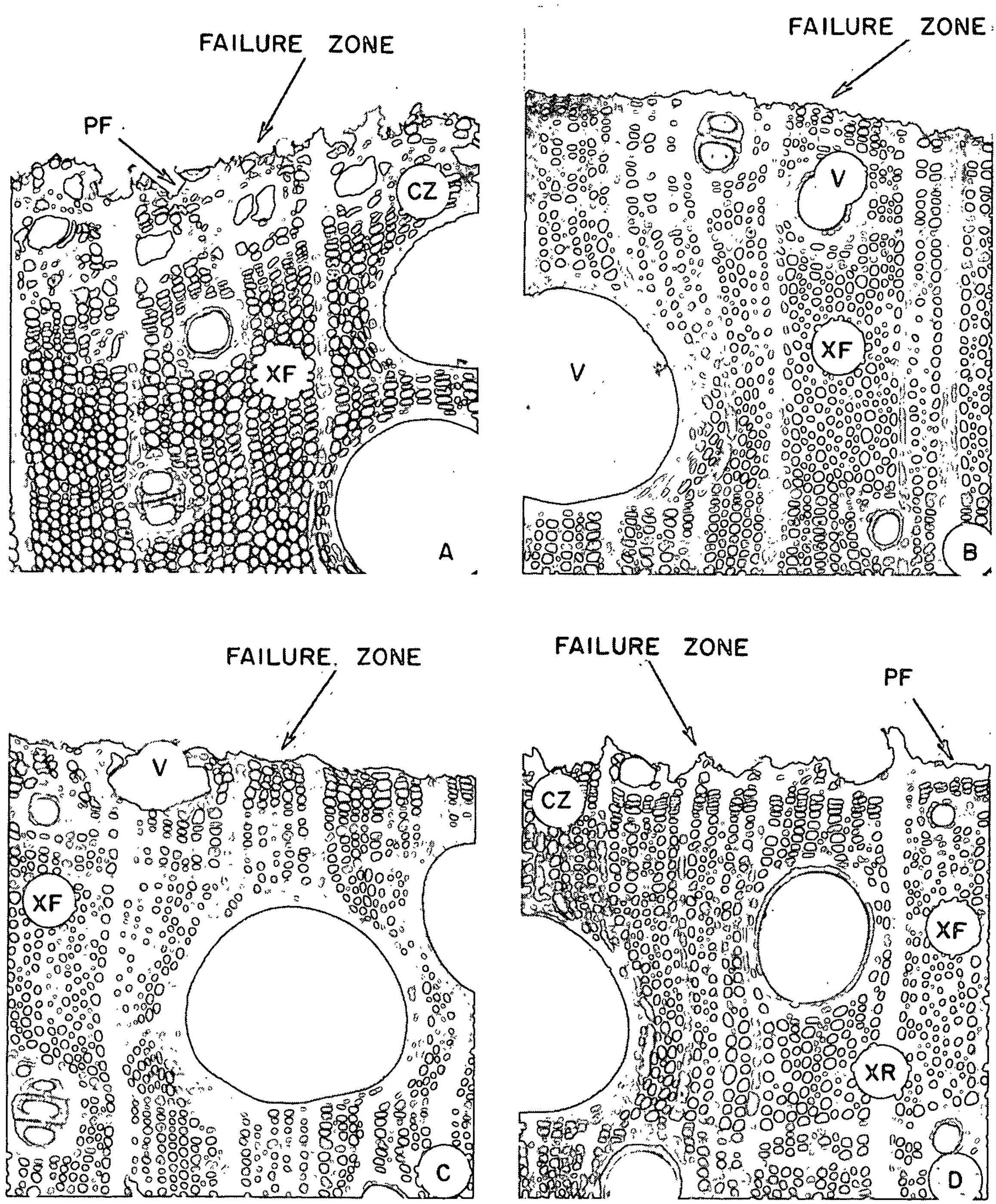


Figure 5. Illustrated Are the Seasonal Changes that Occurred in the Location of the Failure Zone of Shagbark Hickory; A — April 12 Collection, Failure Occurred in Inner Bark Between Bands of Phloem Parenchyma and Phloem Fibers (PF); B — May 10 Collection, Failure in the Cambium Zone; C — May 24 Collection, Failure in the Cambium Zone and Nonlignified Xylem Initials; D — August 16 Collection, Failure in the Inner Bark Phloem Parenchyma and Phloem Sieve Tube Zone and Along Phloem Fiber Band (PF). Also Illustrated Are Xylem Fibers (XF), Xylem Rays (XR) and Vessels (V)

dormant season wood/bark adhesion. This is the case with shagbark hickory where the very high dormant season wood/bark adhesion appears to be related to the presence of compactly arranged, wavy bands of thick-walled phloem fibers and the scattered arrangement of the thin-walled sieve tube elements. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Erickson (10) and Arola and Erickson (11) attempted compression debarking on shagbark hickory with poor results. Wood loss tended to be high for this species, especially when one knurled and one smooth roll was used. In a later study, using a combined airlift-vacuum and compression debarking process, Arola, et al. (12) increased the bark removed from a wood/bark chip mixture of hickory to 83% while recovering 88% of the wood.

Chipper trials were also run on shagbark hickory as part of Project 2929. Several bolts were collected in November, stored outside under cover and then thawed and chipped in January. Chipper action was only moderately effective in separating wood and bark. Overall, 55% of the bark had no wood attached. Examination of the chips revealed that in most instances the chipper action was causing separation at the inner bark/outer bark interface rather than at the cambium zone. Chipping to a smaller-sized chip might be one way to improve separation.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of shagbark hickory. (Appendix Tables XXXIX and XL compare the modulus of elasticity of shagbark hickory bark with other species examined in this project.)

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF SHAGBARK HICKORY[a]

Material	Strength	Toughness
Wood	--	1.48
Inner bark	25.0	0.90
Outer bark	72.7	0.71

[a]Measurements average of two trees.

Bark strength values for shagbark hickory inner and outer bark were extremely high and, in fact, higher than for any species examined in this project. Toughness values for both wood and bark were also extremely high. The high bark strength of shagbark hickory appears to be due, at least in part, to the large numbers of thick-walled gelatinous fibers and the absence of sclereids. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. It is difficult to predict from the specific gravity, strength, and toughness measurements whether hammermilling would work well on shagbark hickory because they were all uniformly high. However, it appears a high percentage of bark would be retained on the larger mesh screens in a hammermilling and screening operation simply because of the large amount of stringy fiber in the bark.

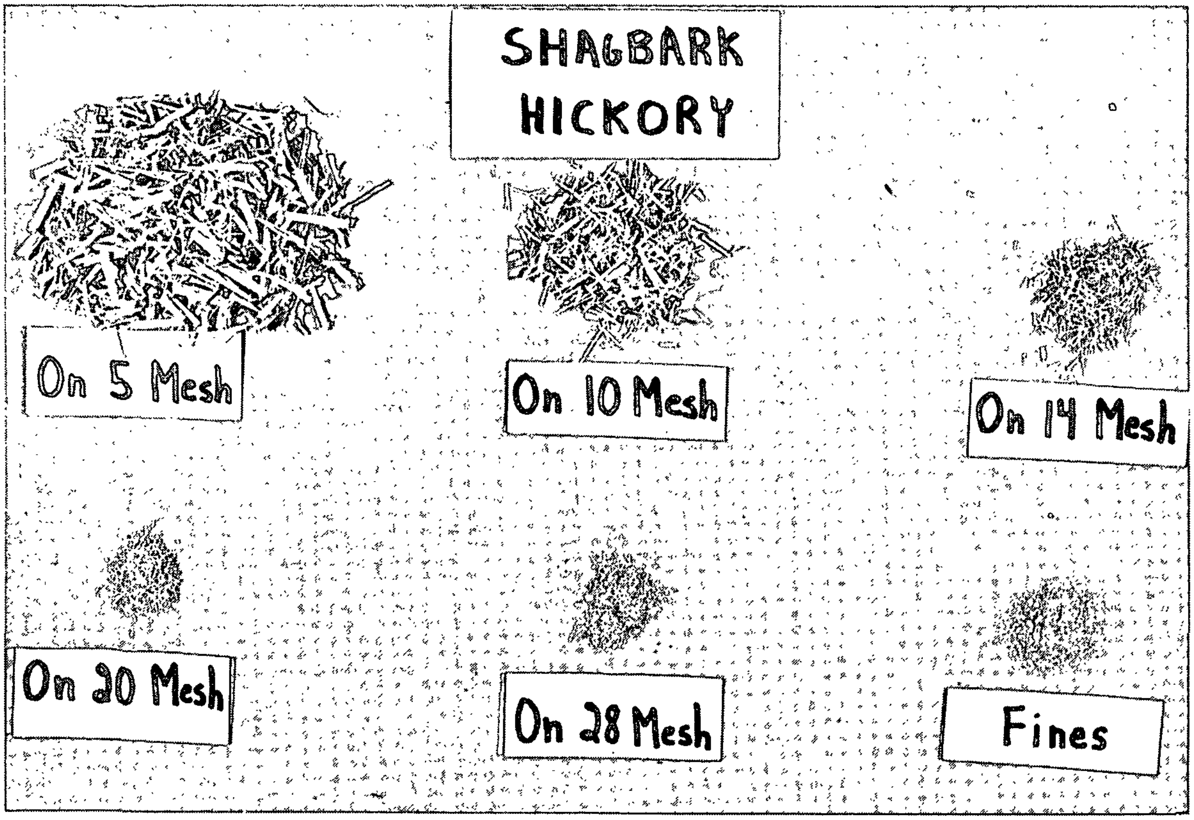
Summarized in Table V are the results of the hammermilling tests run on shagbark hickory wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a low reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and an 11% reduction in levels of bark. This small reduction in bark levels appears to be due to the stringy nature of the bark and its retention on the larger mesh screens. A larger amount of bark could be removed without significantly increasing the wood loss by only retaining the material on the 10-mesh screen (22% bark removal and 7% wood loss). Figure 6 illustrates the effect of hammermilling on wood and bark of shagbark hickory. It is difficult to believe

TABLE V

SUMMARY OF HAMMERMILLING TEST ON SHAGBARK HICKORY

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-122	Bark	51.9	27.6	10.1	3.7	2.5	4.2	Mostly inner bark on larger mesh screens; increasing amounts of outer bark on smaller screens; inner bark stringy in appearance
	Sapwood	76.6	16.4	2.7	1.2	1.1	2.0	
	Heartwood	75.5	17.9	2.6	1.2	1.0	1.9	
3212-124	Bark	45.1	32.3	10.3	3.5	3.0	5.8	Same as above
	Sapwood	79.1	13.7	2.7	1.3	0.9	2.3	
	Heartwood	85.1	9.4	2.0	0.8	0.8	1.8	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



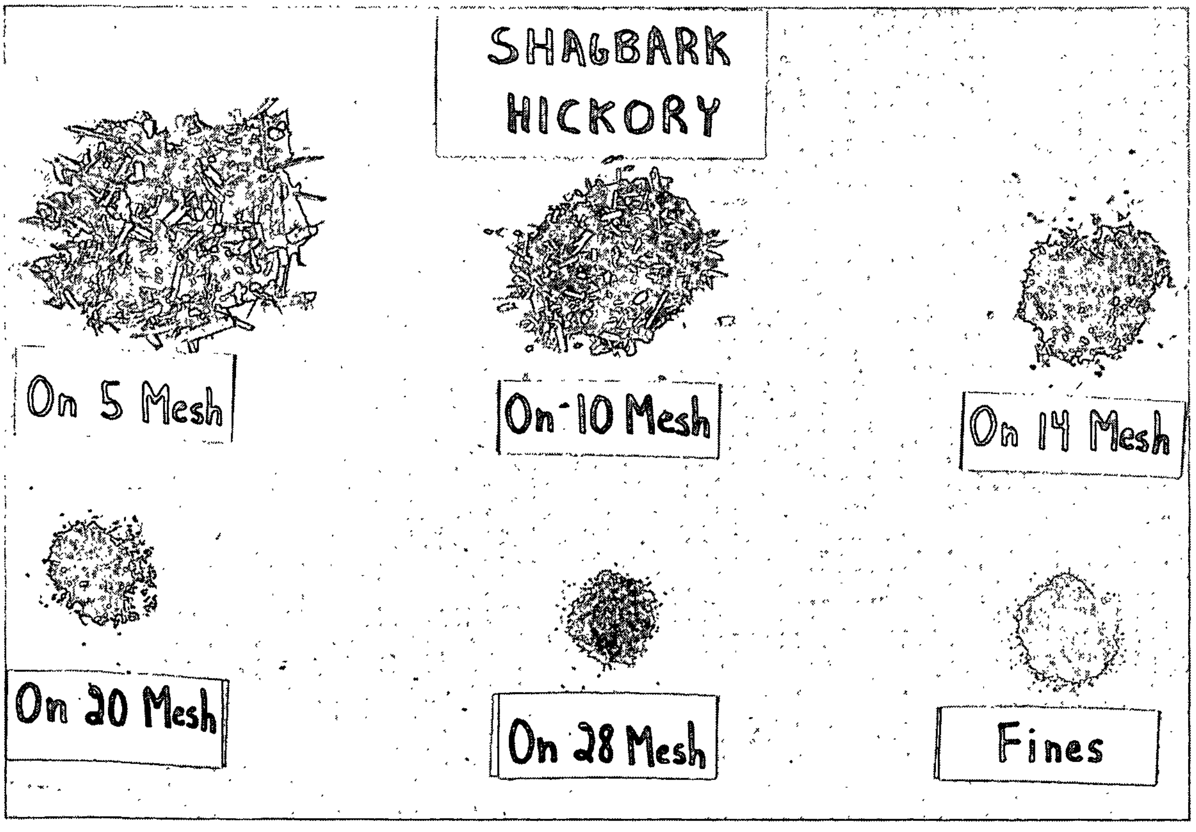


Figure 6. Illustrated Is the Effect of Hammermilling on Shagbark Hickory Wood (Top) and Bark (Bottom)

that additional significant amounts of bark could be removed by improving the screening procedure since the bark is so stringy after hammermilling. Further, it appears that much of the outer bark would be knocked off during handling before chipping and the inner bark could be an additional source of useful fiber. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of shagbark hickory with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two shagbark hickory trees (IPC 3212-122 and IPC 3212-124) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were all close in density at the various moisture contents.

Figure 7 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation would not be possible for shagbark hickory wood and bark chips. Both wood and bark chips would sink at very low moisture contents, i.e., less than 10%.

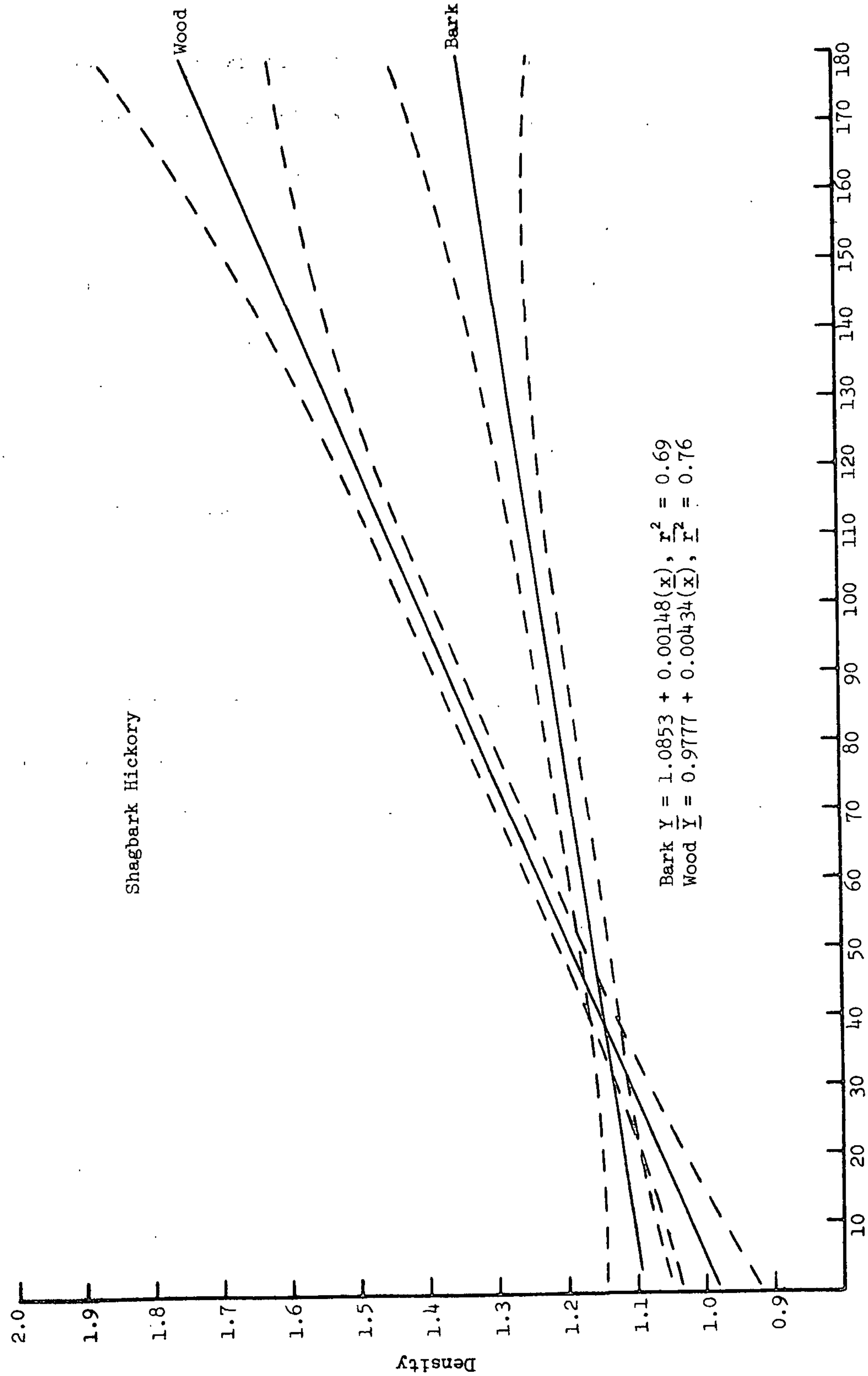


Figure 7. Illustrated Is the Relationship Between Basic Density and Moisture Content for Shagbark Hickory. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell-time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table VI summarizes the results for shagbark hickory. At the moisture content ranges covered by the wood and bark chips (68 to 87%), both fractions should sink according to the density-moisture content curves. Most chips did sink, leaving only a very small percentage floating.

DATA INTERPRETATION

Although shagbark hickory is not a commercially valuable species, it is useful to examine it because it represents an extreme — a species with a large amount of fiber in the bark and one with high bark strength and high wood/bark adhesion.

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR SHAGBARK HICKORY

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-122 Bark	73.0	after 5	95.1	4.9
		15	95.1	4.9
		60	95.1	4.9
		240	97.7	2.3
IPC 3212-122 Sapwood	71.4	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-122 Heartwood	68.4	after 5	97.4	2.6
		15	97.4	2.6
		60	97.4	2.6
		240	100	0
IPC 3212-124 Bark	86.9	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-124 Exterior wood	71.2	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-124 Interior wood	81.3	after 5	100	0
		15	100	0
		60	100	0
		240	100	0

It would be very difficult to separate and segregate the bark of this species from the wood. This is particularly true of the inner bark since a good share of the outer bark would probably be knocked off during handling. The dormant season wood/bark adhesion values obtained were higher than for any other species examined, as were the strength and toughness measurements. Hammermilling wood and bark chips resulted in only an 11% bark removal and 4% wood loss when the material on the 14-mesh screen was retained. The low bark removal was probably caused by the stringy nature of the hammermilled bark which kept it on the larger screens. Water flotation would not be a feasible method of segregation either as both wood and bark tend to sink at low moisture contents.

Pulping shagbark hickory bark resulted in a fibrous yield of 15%, which is more fiber than obtained from any of the other species examined except white ash. Coupled with the high fiber yield is a lack of sclereids in the bark which can contribute to speck problems in some species where sclereid numbers are high. It also appears that strength properties of the pulp are not adversely affected when levels of bark up to 26% are included. Unfortunately, bark extractives values are rather high (14.6%) and could cause a problem if the bark became too concentrated in a particular chip fraction.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (13), Hooper (14), Biltonen, *et al*. (15), Short, *et al*. (16), Miller (17) and Vais and Vostrov (18). A paper by Manwiller (19) examines wood and bark moisture contents of small-diameter hickory among other species while one by Taylor (20) contains information on the effect of extraction on volume dimensions and specific gravity.

BARK AND WOOD PROPERTIES OF POST OAK
[*Quercus stellata* Wangenh.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Post oak, growing on a wide variety of soils and on many sites, is found from southeastern New England westward to southeastern Iowa and eastern Kansas, south to west-central Texas, and east to central Florida. Post oak is confined to poorer sites and tends to be shrubby in the north while in the south it is more numerous and is a larger tree. With blackjack oak and the hickories, it forms the western outposts of the eastern deciduous forests in the southern plains. Gravelly or sandy soils of low organic content are common sites for post oak, such as rocky ridges, sandy outcroppings, and southern exposures. It is also found on sites that are alternately waterlogged and hard and dry such as the Alabama and Mississippi flatwoods. Mature post oaks are from 50 to 60 feet tall and from 12 to 24 inches in diameter in the southeast. In contrast, in the extreme western part of its range, mature trees are seldom over 30 to 40 feet in height and 15 to 18 inches in diameter. Post oak is a slower-growing tree than many of the species associated with it, but tends to persist and become dominant on poor sites because of its drought resistance.

WOOD AND BARK MORPHOLOGY

Wood

The woods of the various oaks belonging to the white oak group cannot be separately identified with certainty. Generally, white oaks have a whitish to light brown sapwood and a rich light brown to dark brown heartwood. The wood has no characteristic odor or taste, is usually straight-grained, heavy, hard, strong in bending and moderately stiff. Growth rings are very distinct, except in slow-grown stock, and the transition from spring- to summerwood is abrupt or somewhat gradual. Abundant parenchyma are visible with a hand lens and are paratracheal, metatrachel-diffuse or metatracheal. Rays are of two types: the broad (oak-type) which are very conspicuous to the naked eye, separated by several to many narrow rays appearing on the tangential surface as rather widely spaced, staggered lines of varying length; and narrow (simple) which are much more numerous than the broad rays but indistinct without magnification. Fibers are medium thick- to thick-walled, frequently gelatinous, and 14-22 microns in diameter.

Bark

The bark is reddish brown in color and typically irregularly plated with loose plates. Sometimes, however, it can be furrowed with narrow ridges. The inner bark for the trees examined averaged 47% but ranged from 32 to 66%. Figure 8 illustrates a cross section of the inner bark of post oak. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

The specimens of post oak bark examined proved extremely difficult to embed properly. However, enough detail was visible to reveal that the crystal content of the phloem was unusually high compared to other species in this report (see photomicrograph) and possibly greater than in any of the previous studied species in this project. Crystalliferous cells included most longitudinal and ray parenchyma as well as many sclereids. Most parenchyma in the large rays were also sclerotic but alternated in radial portions with nonsclerotic parenchyma.

Sclerenchyma in the inner bark was present near the cambium zone as small clusters of fibers with or without a few sclereids. Further away from the cambium

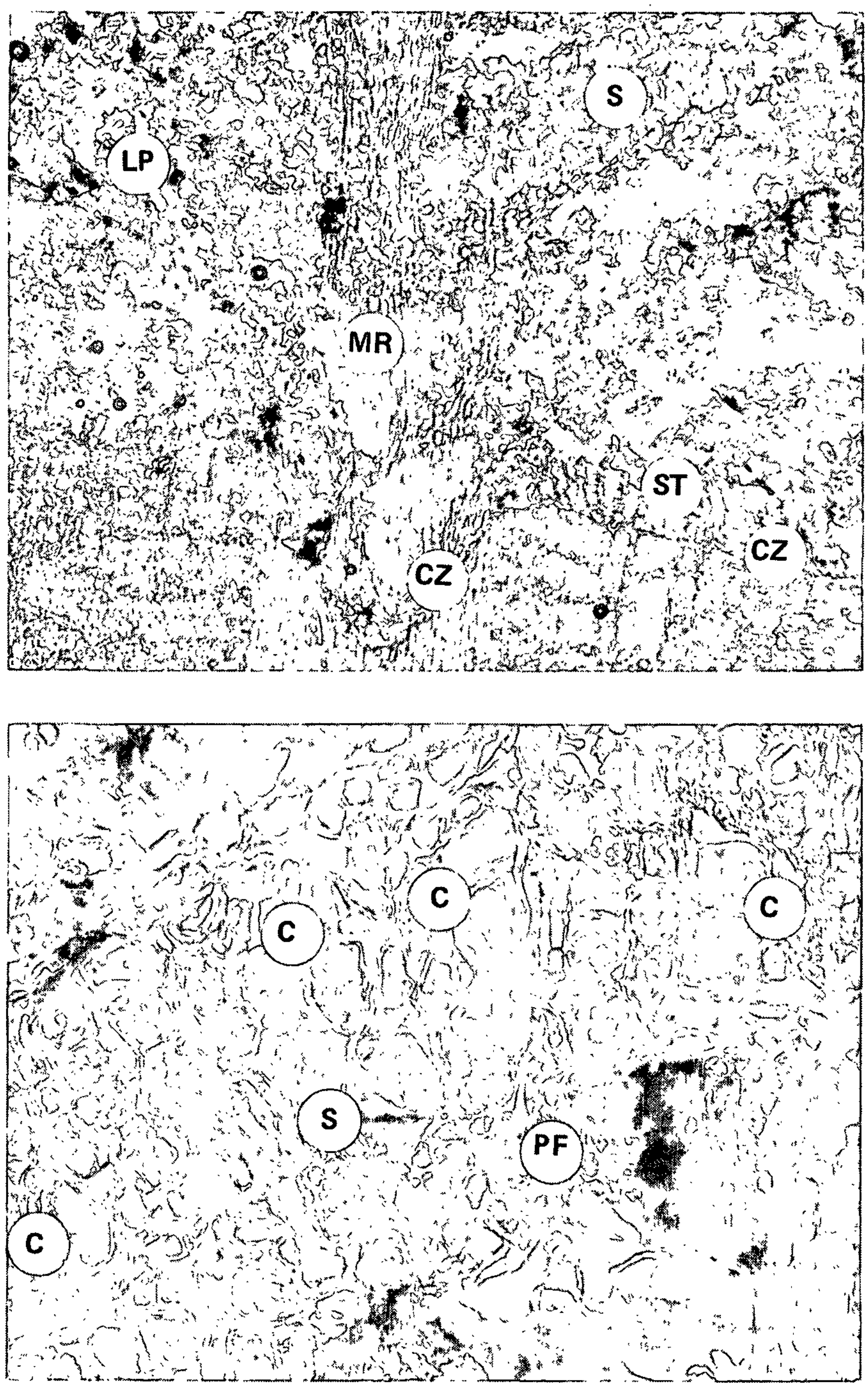


Figure 8. Cross Sections of Post Oak. Photograph on Top Shows Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), Sclereids (S), Longitudinal Parenchyma (LP) and a Multiseriate Ray (MS). Shown on the Bottom, at Increased Magnification, Are the Crystals (C) Found in Post Oak Bark, Phloem Fibers (PF) and Sclereids (S). Magnification — 75X Top, 300X Bottom

zone the proportion of sclereid cells increased noticeably. This trend was also characteristic of the large rays. The latter, in general, also tended to be more sclerotic and crystalliferous than any of the small rays observed.

The cambium zone of the large rays here extended inwardly as in the beech and pin oak, but the phloem ray parenchyma just outside the cambium zone were not sclerotic, only crystalliferous. Perhaps this situation had some influence on the wood/bark adhesion tests of the specimens, which showed a tendency for no ray pullout.

The crystals in post oak are more than likely calcium oxalate and can be expected to add to abrasion and recovery furnace problems. The large amount of crystals found in post oak is reflected in the ash and calcium content of the bark (see Table XXXII). Both values were very high for this species.

The outer bark of post oak, although almost impossible to section properly, appeared to be relatively similar in morphology to other oak species.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

Specific Gravity

Table VII summarizes the information available on wood and bark of post oak. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of post oak at several moisture contents.

TABLE VII

POST OAK SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

	Bark			
Wood Average	Inner	Outer	Total	References and Remarks
0.63				Taylor (3)
0.60				Bendtsen and Ethington (6)
0.66			0.50	Manwiller (4)
0.60				IUFRO (7)
0.58 (sapwood) 0.66 (heartwood)	0.61	0.49	0.56	IPC 3212-120
0.63 (sapwood) 0.71 (heartwood)	0.66	0.56	0.61	IPC 3212-125
0.63 (sapwood) 0.71 (heartwood)	0.68	0.54	0.57	IPC 3212-126

An average specific gravity (ovendry weight/green volume) of approximately 0.64 appears appropriate for the wood of post oak. Our samples were divided into sapwood and heartwood and specific gravity determinations made on each. Our limited data showed the heartwood to be slightly higher in specific gravity than the sapwood.

The specific gravity of the total (inner + outer) bark of post oak is somewhat less than that of the wood. The inner bark was higher in specific gravity than the outer bark on all three trees examined in this project. Overall values suggested for use in species comparisons are 0.64 for wood and 0.65, 0.53 and 0.56 for inner, outer and total bark. These values are close to those reported for white oak (Quercus alba), characterized in Progress Report Four.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

No information was found in the literature on alcohol-benzene extractives and the table includes only IPC information. Table VIII summarizes these measurements. Post oak wood is fairly low in extractives and a level of 4.3% is suggested for use in between-species comparisons. Extractives work done on post oak bark in this project showed an average level of 8.2%. These values are very close to those reported for southern white oak and summarized in Table XXXIV of the "Between Species Comparisons" section. Bark extractives levels are relatively low and should not be much of a problem except possibly in those cases where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical treatments.

TABLE VIII

POST OAK EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	3.9	IPC 3212-120
Wood	3.7	IPC 3212-125
Wood	5.4	IPC 3212-126
Bark	8.1	IPC 3212-126
Bark	9.7	IPC 3212-125
Bark	6.7	IPC 3212-120

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped post oak bark.

The short, thin-walled sieve tubes (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, most of the sclereids in the pulped post oak bark went through the 200-mesh screen and would not be a factor in the usable pulp.

As a check on pulp yield and the nature of the material produced from post oak, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table IX summarizes the results of this investigation. Micro-pulping post oak bark resulted in a yield of 41 to 51% solids. When screened, the coarse screens (60 and 100-mesh) retained mostly phloem fibers. The on 150-mesh screen contained many phloem fibers and some sieve tubes. The on 200-mesh and through 200-mesh screens had large numbers of sieve tubes and some fibers, sclereids and parenchymatous cells. Figure 9 illustrates the type of material on the 60-mesh screen.

TABLE IX

POST OAK MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-120	3212-125	Remarks[a]
Yield, % solids	50.7	41.7	
Fraction			
On 60 mesh, %	7.4	2.8	The fraction contained 100% phloem fibers. Average arithmetic length of the phloem fibers was 1.04 mm
On 100 mesh, %	2.9	2.3	The fraction contained mainly phloem fibers (>95%) with small percentages of sieve tubes (<5%) and crystalliferous parenchyma (<5%)
On 150 mesh, %	1.2	1.2	The fraction contained a large percentage of phloem fiber (70-80%), a smaller percentage of sieve tubes (20-30%), and a trace of crystalliferous parenchyma
On 200 mesh, %	2.5	0.5	The fraction contained mostly sieve tubes (60-70%) and phloem fiber (25-35%), with small percentages of parenchymatous cells (<5%), sclereids (<1%), and crystalliferous parenchyma (<1%)
Through 200 mesh, %	86.0	93.2	The fraction contained a large percentage of sieve tubes (45-55%) and smaller percentages of parenchymatous cells (15-25%), sclereids (15-25%), crystalliferous parenchyma (<10%) and phloem fibers (<10%)

[a]Percentages given are on a dry weight basis.

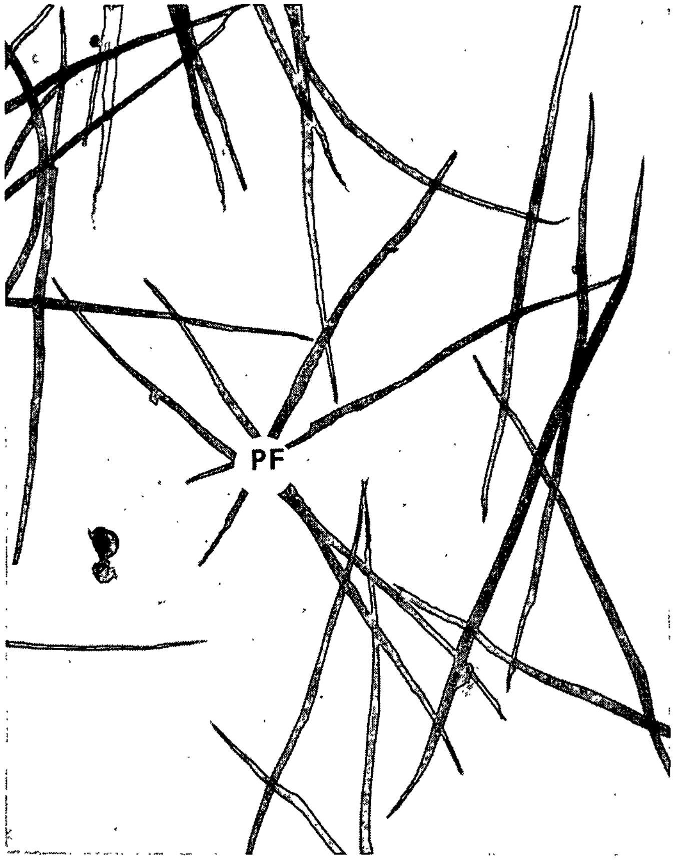


Figure 9. The 60-Mesh Screen Contained by Weight 100% Phloem Fibers (PF). Magnification — 75X

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 47 grams of solids will result. Of this 47 grams, about 3.5 grams (3.5%) of phloem fibers and 0.1 gram (0.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was comparable to the other oaks investigated in this project. Average arithmetic length of the bark fibers was 1.04 mm, compared to a wood fiber length of 1.29 mm as reported by Taylor (3). Both measurements are on whole fibers, selected in an unbiased manner.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for post oak samples collected February 24 and March 17. After testing, the samples were examined to determine the location of the zone of failure. The failure zone was very similar in nature to that of pin oak, described in the next section, occurring between tangentially disposed lines of fiber groups and sieve-tube members and parenchyma in the phloem. The failure was located approximately 0.2-0.4 mm from the cambium zone. One feature of the wood/bark failure specimen examined that rendered it somewhat different from the other oaks examined in this project was that it did not exhibit xylary ray pull-out of its large rays. This could have been due to the fact that no sclereids or sclerotic ray parenchyma were seen in the phloem of the test sample near the cambium zone, only clusters of phloem fibers. Adhesion measurements averaged 12.2 kg/cm^2, a moderate value. Due to problems in embedding and sectioning, no photomicrographs could be taken of the failure zone of post oak.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with post oak. In the oaks, sycamore, and beech, xylary rays may also contribute to higher adhesion values, especially where sclerenchyma in the rays are lignified immediately adjacent to the cambium. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Arola and Erickson (11) attempted compression debarking on post oak with promising results. Wood loss averaged only 5.1% with bark removal of 11.1% from an original bark input of 14.2%.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of post oak. (Appendix Tables XXXIX and XL compare the modulus of elasticity of post oak bark with other species examined in this project.)

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF POST OAK[a]

Material	Strength	Toughness
Wood	--	0.66
Inner bark	6.8	0.20
Outer bark	3.4	0.18

[a]Determinations average of two trees, except inner bark strength which is based on three trees.

Bark strength values were moderate for post oak inner bark and low for the outer bark. Toughness values for both wood and inner bark were intermediate compared to other species examined while the outer bark was fairly strong. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the moderate specific gravity of the bark and the intermediate strength and toughness measurements for the inner bark and the confounding results for the outer bark, it is difficult to predict the effect of hammermilling or a similar mechanical action on wood/bark chip mixtures. The results are not as clear cut as they are for some species.

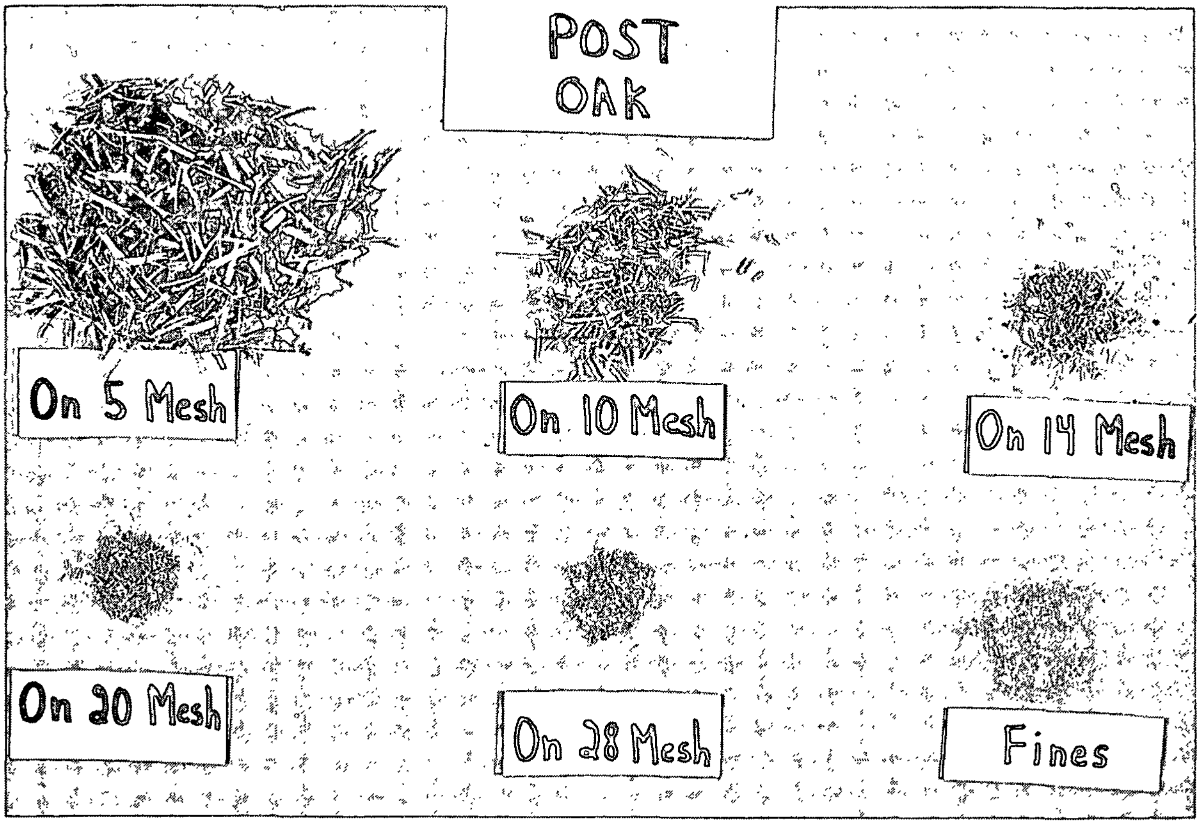
Summarized in Table XI are the results of the hammermilling tests run on post oak wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a fairly good reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 6% wood loss and a 47% reduction in levels of bark. This is one of the highest amounts of bark removed by hammermilling to date and was also accompanied by a relatively low wood loss. Reduction in levels of bark was greater than it was for white oak, although the wood loss was not greatly different. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (62% bark removal and 10% wood loss). Since post oak bark contains fiber, the increased wood loss may not justify the additional bark removal. Figure 10 illustrates the effect of hammermilling on wood and bark of post oak. It is possible that a quick segregation could be made by screening,

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON POST OAK

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-120	Bark	21.5	20.1	15.3	7.0	9.4	26.7	Approximately 2/3 inner bark on larger mesh screens; increasing amounts of outer bark on smaller mesh screens
	Sapwood	66.6	18.0	6.6	2.7	2.0	4.0	
	Heartwood	70.6	18.5	4.8	1.3	1.7	3.1	
3212-125	Bark	7.5	26.1	14.6	10.3	12.6	28.9	Equal amounts of inner and outer bark distributed throughout screens
	Sapwood	81.1	12.3	1.8	0.8	1.0	3.1	
	Heartwood	77.4	14.3	3.2	1.9	0.9	2.4	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



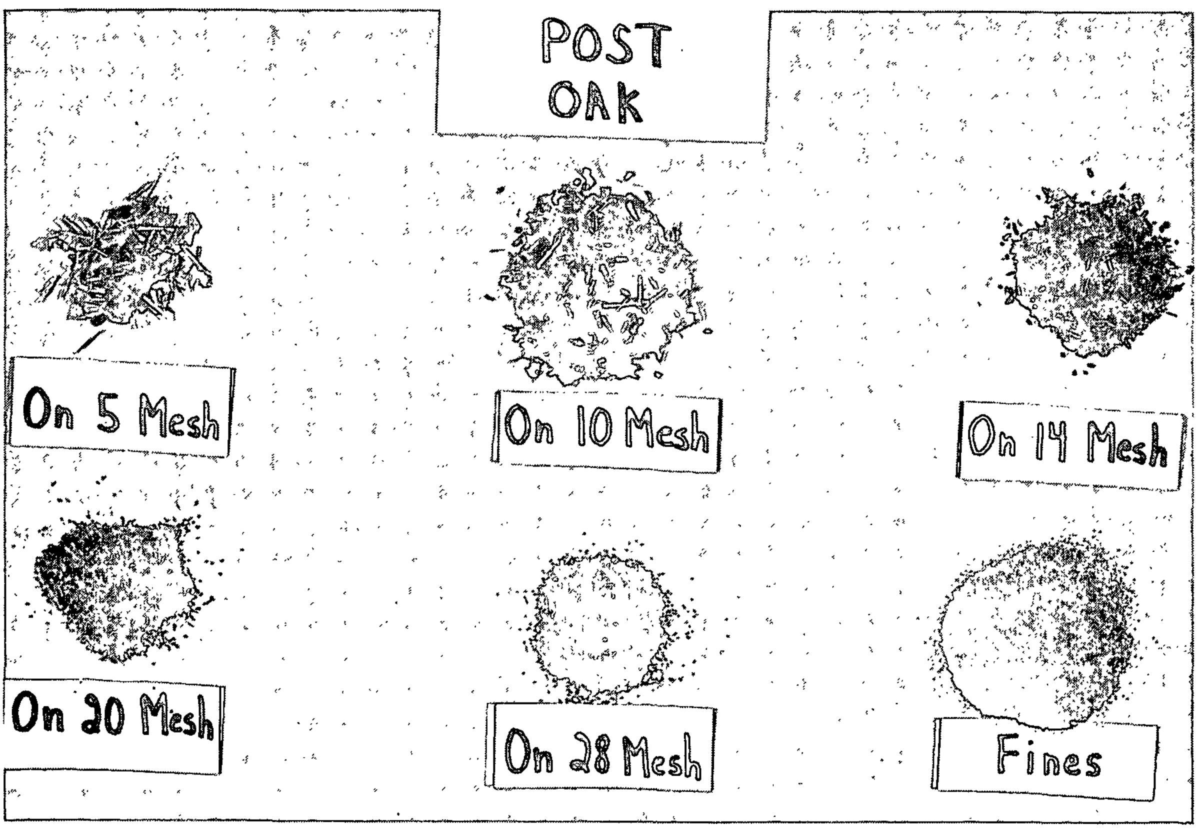


Figure 10. Illustrated Is the Effect of Hammermilling on Post Oak Wood (Top) and Bark (Bottom)

hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method or used as a source of fuel. It would not be possible to take advantage of the differences in configuration of wood and bark chips in screening as the bark is long and stringy due to the fiber it contains. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of post oak with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two post oak trees (IPC 3212-120 and IPC 3212-125) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Outer and total bark were similar in density while inner bark was higher in density at comparable moisture contents.

Figure 11 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation would not be possible for post oak wood and bark chips. The two fractions have similar densities at moisture contents below approximately 40% and at higher moisture contents both fractions would sink.

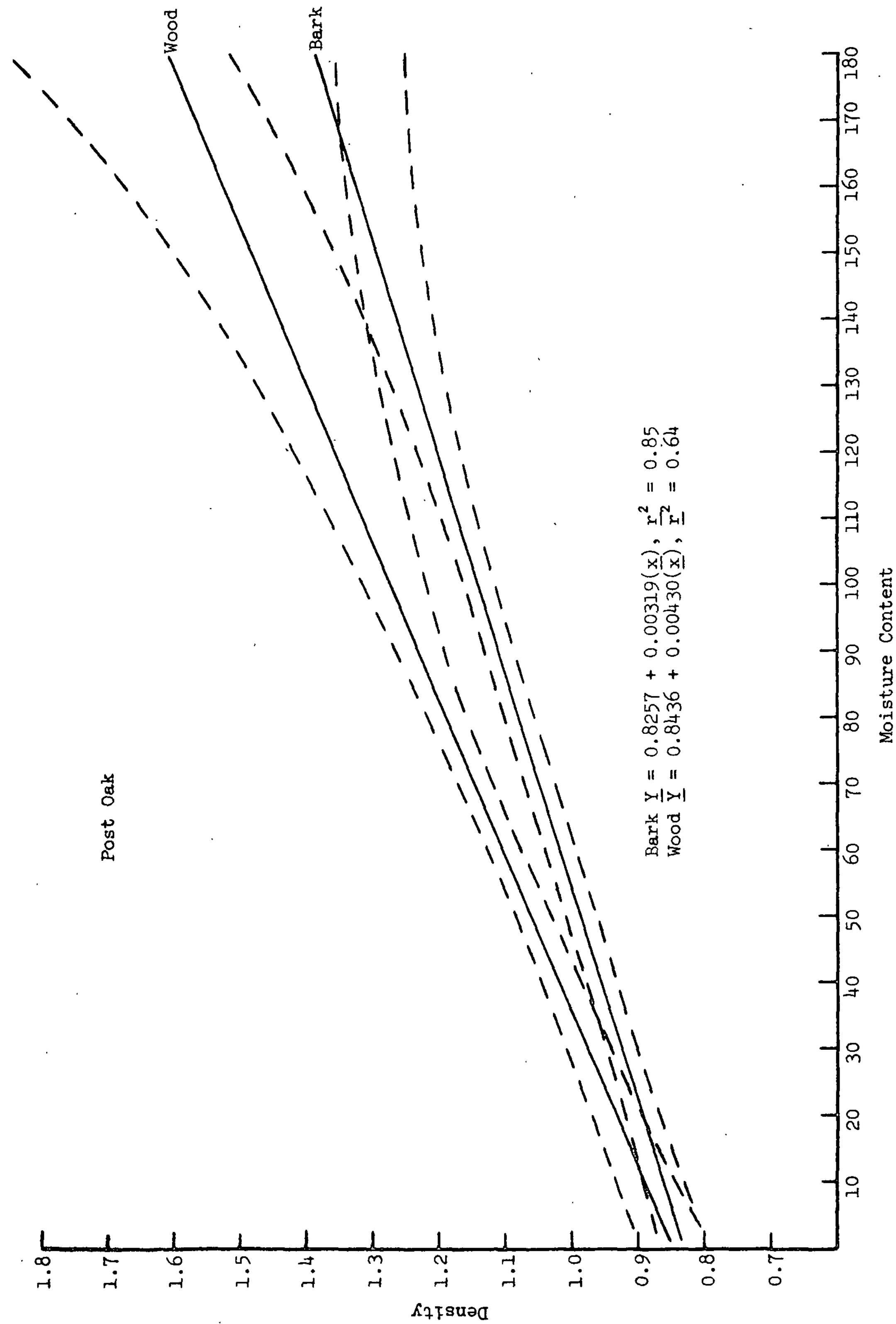


Figure 11. Illustrated Is the Relationship Between Basic Density and Moisture Content for Post Oak. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XII summarizes the results for post oak. Tree 3212-125 behaved as expected from the density-moisture content curves. However tree 3212-120 had more bark and sapwood floating than would have been expected. Both the wood and bark specific gravity of 3212-120 are lower than that for 3212-125 and this also carried over into the densities at various moisture contents. It is possible that chips from the particular bolt used of this tree were low enough in density to keep a greater share of them floating.

DATA INTERPRETATION

The bark of post oak contains some fiber. For every 100 grams of bark that is pulped, approximately 3.5 grams of fiber would be produced. Most of the

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR POST OAK

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-120	86.5	after 5	78.8	21.2
Bark		15	78.8	21.2
		60	78.8	21.2
		240	83.1	16.9
IPC 3212-120	77.1	after 5	62.9	37.1
Sapwood		15	62.9	37.1
		60	62.9	37.1
		240	73.3	26.7
IPC 3212-120	71.9	after 5	95.2	4.8
Heartwood		15	95.2	4.8
		60	95.2	4.8
		240	97.3	2.7
IPC 3212-125	70.5	after 5	96.7	3.3
Bark		15	96.7	3.3
		60	96.7	3.3
		240	98.0	2.0
IPC 3212-125	78.5	after 5	100	0
Sapwood		15	100	0
		60	100	0
		240	100	0
IPC 3212-125	59.0	after 5	100	0
Heartwood		15	100	0
		60	100	0
		240	100	0

sclereids present in the bark would be lost in washing and cleaning operations and shouldn't cause much of a problem in the pulp. With the fiber yield, lack of large amounts of sclereids and low bark extractives (8%), this species may be a suitable candidate in some instances for pulping with the bark.

Although segregation through water flotation does not appear possible for this species, other separation and segregation techniques have some promise. Hammermilling wood and bark chips resulted in high bark removal (47%) and a relatively small wood loss (6%) when material on the 14-mesh screen was retained. Compression debarking also gave promising results according to the literature. Separation of wood and bark through chipper action also appears to have some possibility. Bur oak, a closely related member of the white oak family, had 10% or less of the bark chips with wood attached after chipping during the dormant season. It is possible that a quick segregation could be made by screening, hammermilling or compression debarking the fractions high in bark and rescreening.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (13), Hooper (14), Biltonen, et al. (15), Short, et al. (16), Miller (17) and Vais and Vestrev (18). A paper by Manwiller (19) examines wood and bark moisture contents of small-diameter hardwoods while papers by Powell, et al. (21) and Barker (22) deal with whole-tree chips and short-rotation hardwoods.

BARK AND WOOD PROPERTIES OF PIN OAK
[Quercus palustris Muenchh.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Pin oak grows in a moderately wide range of climatic conditions. It is found as far north as northern Illinois, southern Michigan and extreme southern Ontario. To the east it is found in the western and southern halves of Pennsylvania, in New Jersey and in parts of New York and the New England States. It grows through Virginia in the south and into central North Carolina (except most of the Appalachians), and southwestwardly through Tennessee into central Arkansas. To the west, the tree is found in northeastern Oklahoma, in southeastern Kansas, in Missouri, and in southeastern Iowa. Pin oak grows well on wet sites and on heavy soils with poor drainage. It persists over large areas because of its vigor on wet, shallow, often-flooded, heavy-textured soils. It usually grows on flat or nearly flat land and is rarely found on sloping or hilly uplands or at elevations above 800 feet. Height and diameter growth are rapid for this species, and it normally averages 70 to 90 feet in height and 2 to 3 feet in diameter. Pin oak sprouts vigorously from the stumps of small trees and reaches physiological maturity in 80 to 100 years.

WOOD AND BARK MORPHOLOGY

Wood

The woods of the various red oaks cannot be separated from each other with certainty. In general, the wood is hard and heavy. The heartwood appears pinkish to pale reddish brown, while the sapwood is whitish to grayish or light reddish brown. A ring-porous wood, the growth rings are very distinct and earlywood (springwood) pores are large, forming a conspicuous band 1-4 pores in width. The transition to latewood (summerwood) is gradual to more or less abrupt, and the pores are more abundant, round, small, thick-walled and less distinct. The largest vessels are 200-430 μm in diameter in the earlywood, and number 10-30 per sq mm in the latewood. Rays, also conspicuous to the naked eye, are unstoried, homogeneous, and of two types. The broad rays are approximately 12-30 seriate and 150-400+ μm in diameter. On a tangential surface, these broad rays are separated by numerous narrow rays, usually uniseriate and very variable in height, 1-20+ cells. Paratracheal parenchyma intermingle with tracheids, forming part of the conjunctive tissue between the earlywood pores and the rays, and composing most of the light-colored tissue in the latewood vessel area. Very abundant, the parenchyma are usually metatracheal or metatracheal-diffuse, usually zonate in fine, more or less regular, tangential lines in the outer portion on the ring. Red oak fibers, medium thick to thick-walled, measure 14-22 μm in diameter and average 1.4 mm in length.

Bark

The bark of pin oak is thick, gray-brown and smooth. The inner bark for the trees examined averaged 47%. Figure 12 illustrates a cross section of the inner and outer bark of pin oak. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

Near the cambium zone, the phloem is characterized by interrupted, tangential lines of fiber clusters as well as narrow and wide (multiseriate) rays. The fiber clusters may or may not also contain a few sclereids; scattered small clusters of sclereids are also present. Some of the fibers are gelatinous.

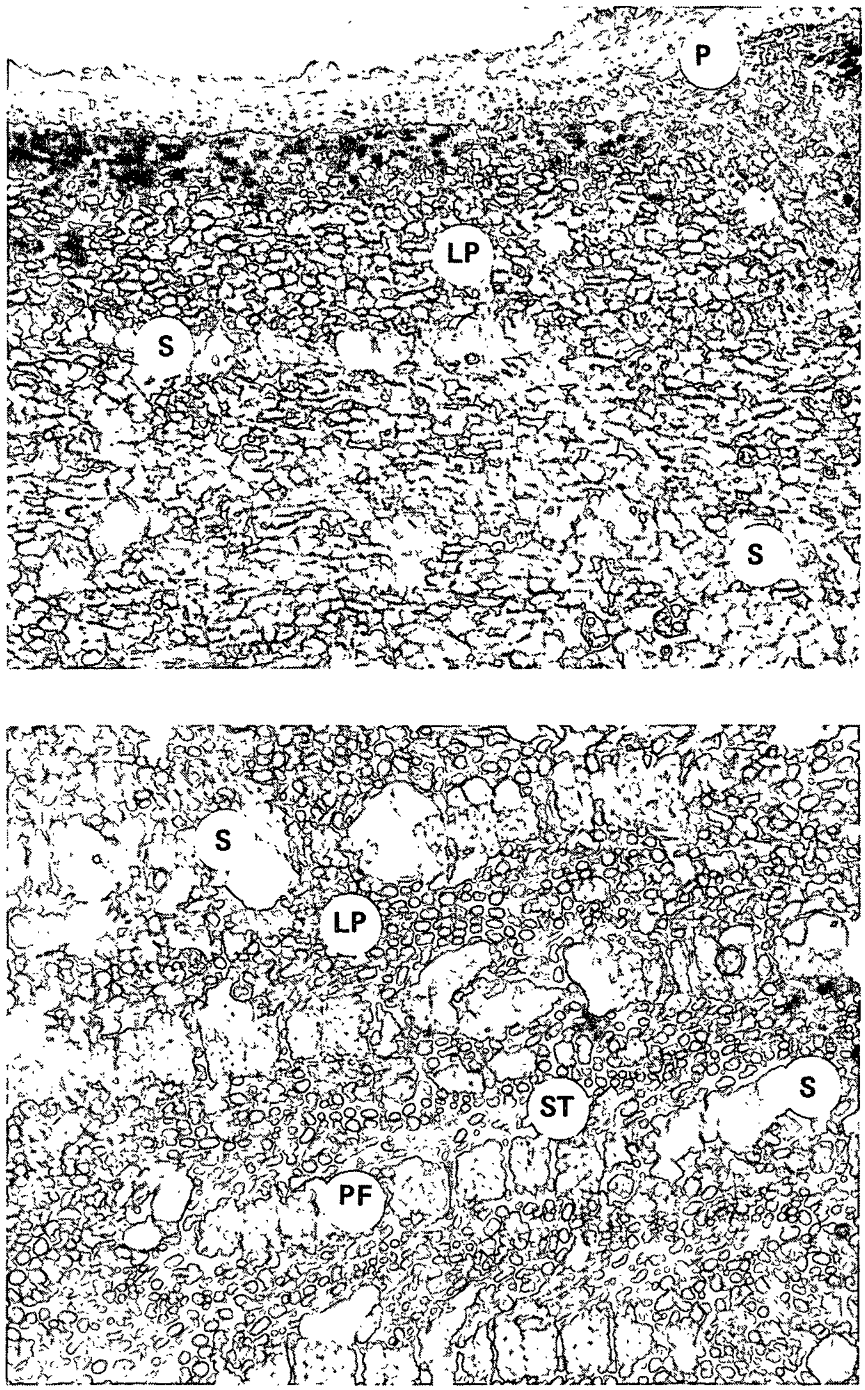


Figure 12. Cross Sections of Pin Oak. Photograph on Top Shows the Inner and Outer Bark, Including Sclereids (S), Longitudinal Parenchyma (LP) and a Periderm Layer (P). The Photomicrograph on the Bottom Shows Only the Inner Bark with Phloem Fibers (PF), Sclereids (S), Sieve Tubes (ST) and Longitudinal Parenchyma (LP). Magnification — 75X

Both longitudinal and ray parenchyma may be sclerotic, the latter especially in the large rays and even just outside the cambium zone. Further out, the tangentially arranged groups of fibers and masses of sclereids are somewhat larger than nearer the cambium zone. Also, most sieve tubes are crushed.

The outer bark is composed of several intergrading periderms with parenchyma, sclereids, and fibers being cut off from the inner bark by more recent periderms. The outermost periderm in this sample was about 1 mm from the next series of inner ones. Phelloderm or sclerotic parenchyma cells beneath the outermost phellogen were largely tanniferous.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIII summarizes the information available on wood and bark of pin oak. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of pin oak at several moisture contents.

TABLE XIII

PIN OAK SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.64				U.S. For. Prod. Lab. (23)
0.58				IUFRO
0.62 (exterior) 0.63 (interior)	0.59	0.72	0.72	IPC 3212-127
0.57 (exterior) 0.60 (interior)	0.59	0.71	0.68	IPC 3212-128
0.62 (sapwood) 0.61 (heartwood)	0.53	0.79	0.73	IPC 3212-130

An average specific gravity (ovendry weight/green volume) of approximately 0.61 appears appropriate for the wood of pin oak. Our samples were divided into interior and exterior wood and, in one case, into heartwood and sapwood. Although the sapwood was distinct on all three trees, it comprised too narrow an area to obtain enough simulated chips for two of the trees. For 3212-127, the interior wood constituted the first 20 rings out of approximately a total of 48 rings, while for 3212-128, it constituted the first 25 rings out of a total of 55 rings. Our limited data showed both the sapwood and heartwood and the exterior and interior wood to be very close in specific gravity.

The specific gravity of the total (inner + outer) bark of pin oak is somewhat higher than that of the wood. The outer bark was higher in specific gravity than the inner bark on all three of the trees examined in this project.

Overall values suggested for use in species comparisons are 0.61 for wood and 0.57, 0.74 and 0.71 for inner, outer and total bark. Pin oak, which is in the red oak group, has comparable wood and bark specific gravities to southern red oak.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

No information was found in the literature on alcohol-benzene extractives and the table includes only IPC information. Table XIV summarizes these measurements. Pin oak wood is fairly low in extractives and a level of 4.4% is suggested for use in between-species comparisons. Extractives work done on pin oak bark in this project showed an average level of 14.9%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE XIV

PIN OAK EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	5.8	IPC 3212-127
Wood	4.3	IPC 3212-128
Wood	3.1	IPC 3212-130
Bark	14.0	IPC 3212-127
Bark	15.3	IPC 3212-128
Bark	15.3	IPC 3212-130

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped pin oak bark.

The short, thin-walled sieve tubes (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, most of the sclereids in the pulped pin oak bark went through the 200-mesh screen and would not be a factor in the usable pulp.

As a check on pulp yield and the nature of the material produced from pin oak, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XV summarizes the results of this investigation. Micropulping pin oak bark resulted in a yield of 24 to 29% solids. When screened, the coarse screens (60 and 100-mesh) retained mostly phloem fibers. The on 150-mesh screen contained many sieve tubes and some fibers and parenchymatous cells. The on 200-mesh and through 200-mesh screens had large numbers of sieve tubes, sclereids and parenchymatous cells. Figure 13 illustrates the type of material retained on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 26 grams of solids will result. Of this 26 grams, about 2.3 grams (2.3%) of phloem fibers and 0.1 gram (0.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to

TABLE XV

PIN OAK MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-127	Sample No. 3212-130	Remarks[a]
Yield, % solids	24.0	29.0	
Fraction			
On 60 mesh, %	4.7	5.5	The fraction contained 100% phloem fiber. Average arithmetic length of the phloem fibers was 1.02 mm
On 100 mesh, %	3.8	4.2	The fraction contained principally phloem fiber (80-90%) with a small percentage of sieve tubes (5-15%) and a trace of parenchymatous cells
On 150 mesh, %	2.5	1.2	The fraction contained a large percentage of sieve tubes (65-75%) with a small percentage of phloem fiber (15-25%), parenchymatous cells (5-15%), and sclereids (<1%)
On 200 mesh, %	2.1	1.3	The fraction contained a large percentage of sieve tubes (65-75%). There were smaller percentages of parenchymatous cells (10-20%), phloem fibers (5-15%), and sclereids (<10%)
Through 200 mesh, %	86.9	87.8	The fraction contained mainly sclereids (40-50%) and parenchymatous cells (40-50%) with small percentages of sieve tubes (<10%) and crystalliferous parenchyma (<5%)

[a]Percentages given are on a dry weight basis.

the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was slightly less than that retained for other oaks investigated in this project.

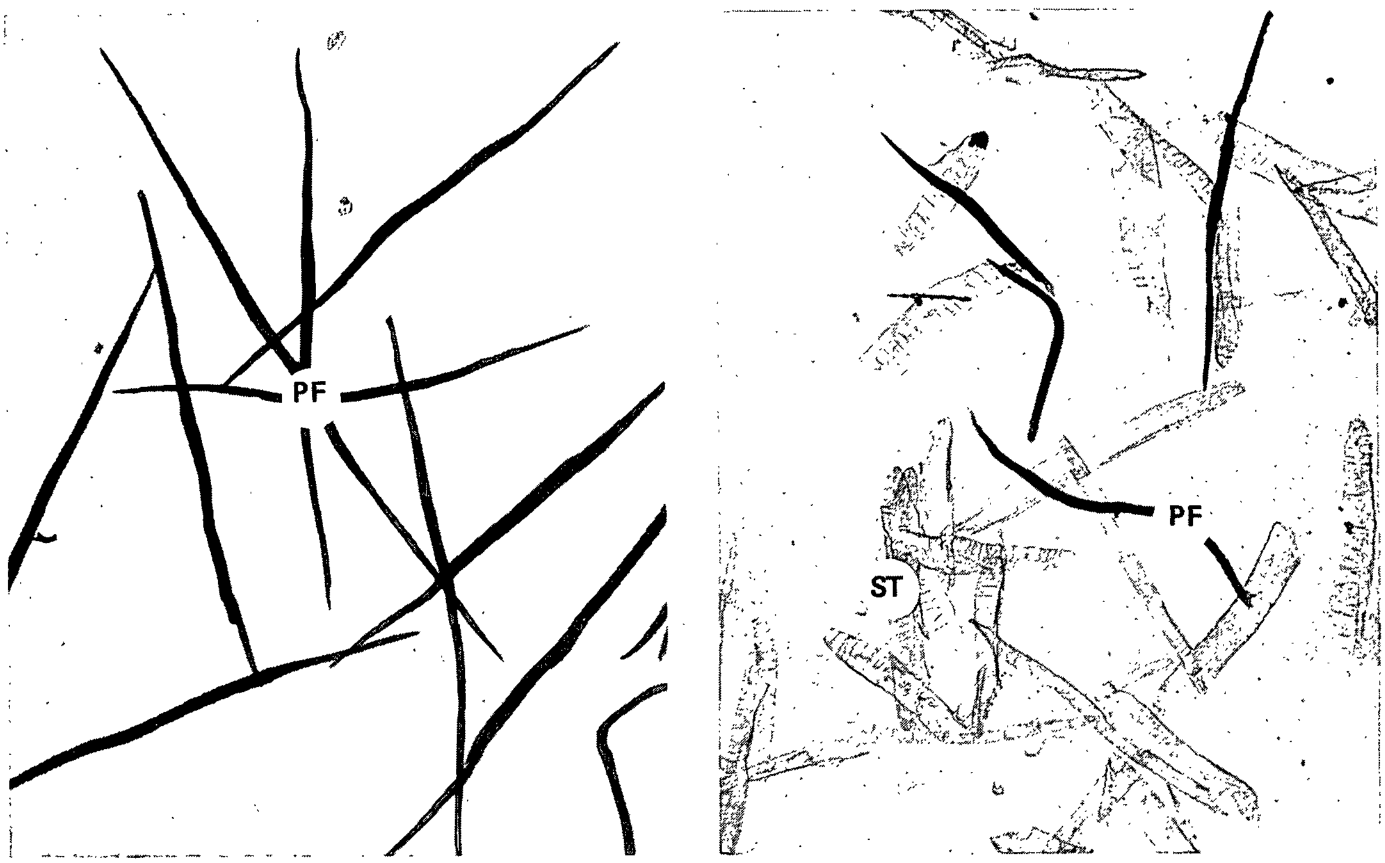


Figure 13. The 60-Mesh Screen (Left) Contained 100% Phloem Fibers (PF). The 150-Mesh Screen (Right) Contained a Large Percentage of Sieve Tubes (ST) with Smaller Percentages of Phloem Fibers. Magnification — 75X

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for pin oak samples collected March 20 and 24. After testing, the samples were examined to determine the location of the zone of failure (see Fig. 14). Most of the failure zone on the sample examined was located in the phloem, about 1.0-1.3 mm from the cambium zone. It was associated with interrupted tangential lines of fiber groups, which also contained a few sclereids. These fiber groups alternated tangentially with sieve-tube elements and phloem parenchyma. Many large rays pulled out of their xylary complement in a manner typical of the oaks, but some large rays did not follow this trend. Even in the rays that did not pull out, however, there were obvious spearheads of sclerotic ray parenchyma terminating at or just inside the cambium zone. Adhesion measurements averaged 12.9 kg/cm^2, a moderate value and similar to post oak.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology.

The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with pin oak. High numbers of sclereids and/or a lack of and the presence of relatively few phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

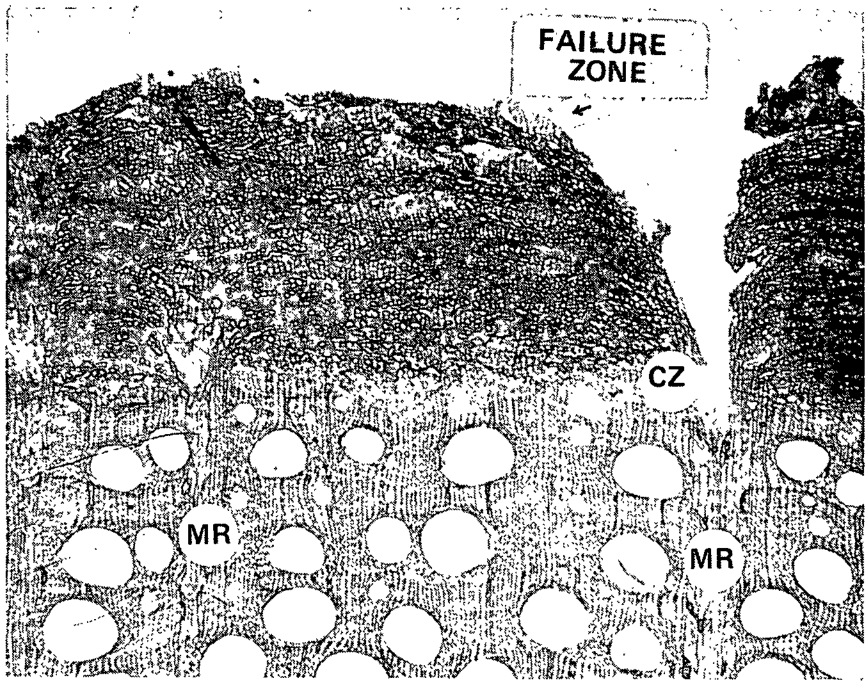


Figure 14. Illustrated Is the Dormant Season Adhesion Zone for Pin Oak. Failure Generally Occurred in the Phloem, About 1.0-1.3 mm from the Cambium Zone. Magnification — 45X. Symbols Illustrate Multiseriate Rays (R), and Cambium Zone (CZ)

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of pin oak. (Appendix Tables XXXIX and XL compare the modulus of elasticity of pin oak bark with other species examined in this project.)

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF PIN OAK[a]

Material	Strength	Toughness
Wood	--	0.64
Inner bark	10.5	0.24
Outer bark	9.9	0.14

[a]Determinations average of two trees, except inner bark strength which is based on three trees.

Bark strength values for pin oak inner bark were high compared to other hardwoods tested thus far. Outer bark values were also high. Toughness values for the sapwood were intermediate while those for inner and outer bark were moderately high. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the rather high specific gravity of the bark and the moderately high strength and toughness measurements, it appears hammermilling might give only intermediate results.

Summarized in Table XVII are the results of the hammermilling tests run on pin oak wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in an intermediate reduction in levels of bark. When the half-sized chips for the two trees (3212-127 and 3212-130) were hammermilled and the material on the 14-mesh screen retained, the result was a 6% wood loss and a 33% reduction in levels of bark. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (46% bark removal and 9% wood loss). Since pin oak bark contains fiber, the increased wood loss may not justify the additional bark removal. Figure 15 illustrates the effect of hammermilling on wood and bark of pin oak. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It would not be possible to take advantage of the differences in configuration of wood and bark chips in screening as the bark is long and stringy

TABLE XVII

SUMMARY OF HAMMERMILLING TEST ON PIN OAK

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-127	Bark	21.1	31.3	13.6	6.4	9.6	18.1	Equal amounts of inner and outer bark distributed throughout screens
	Exterior wood	73.6	14.8	3.4	3.3	1.3	3.7	
	Interior wood	84.7	8.4	2.2	1.1	1.3	2.2	
3212-130	Bark	27.4	28.6	11.6	5.0	7.1	20.3	Same as above
	Sapwood	83.3	7.5	2.9	1.7	1.6	3.0	
	Heartwood	84.1	7.7	2.0	1.9	1.7	2.6	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

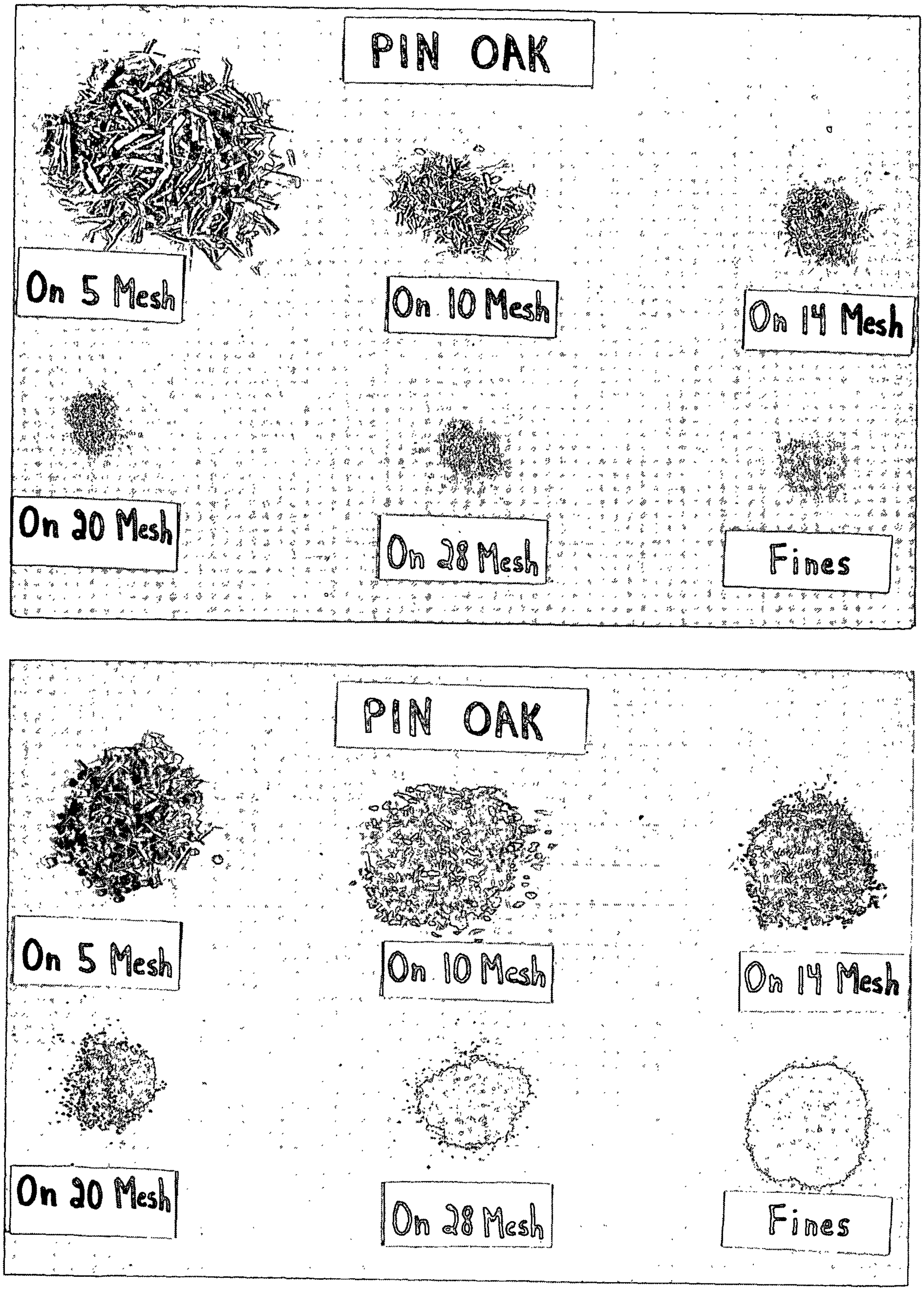


Figure 15. Illustrated Is the Effect of Hammermilling on Pin Oak Wood (Top) and Bark (Bottom)

due to the fiber it contains. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of pin oak with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two pin oak trees (IPC 3212-127 and IPC 3212-130) were used in making the determinations. The moisture

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Wood and inner, outer and total bark were all similar in density at the various moisture contents.

Figure 16 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation would not be possible for pin oak wood and bark chips. Both fractions are too close in density at similar moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a

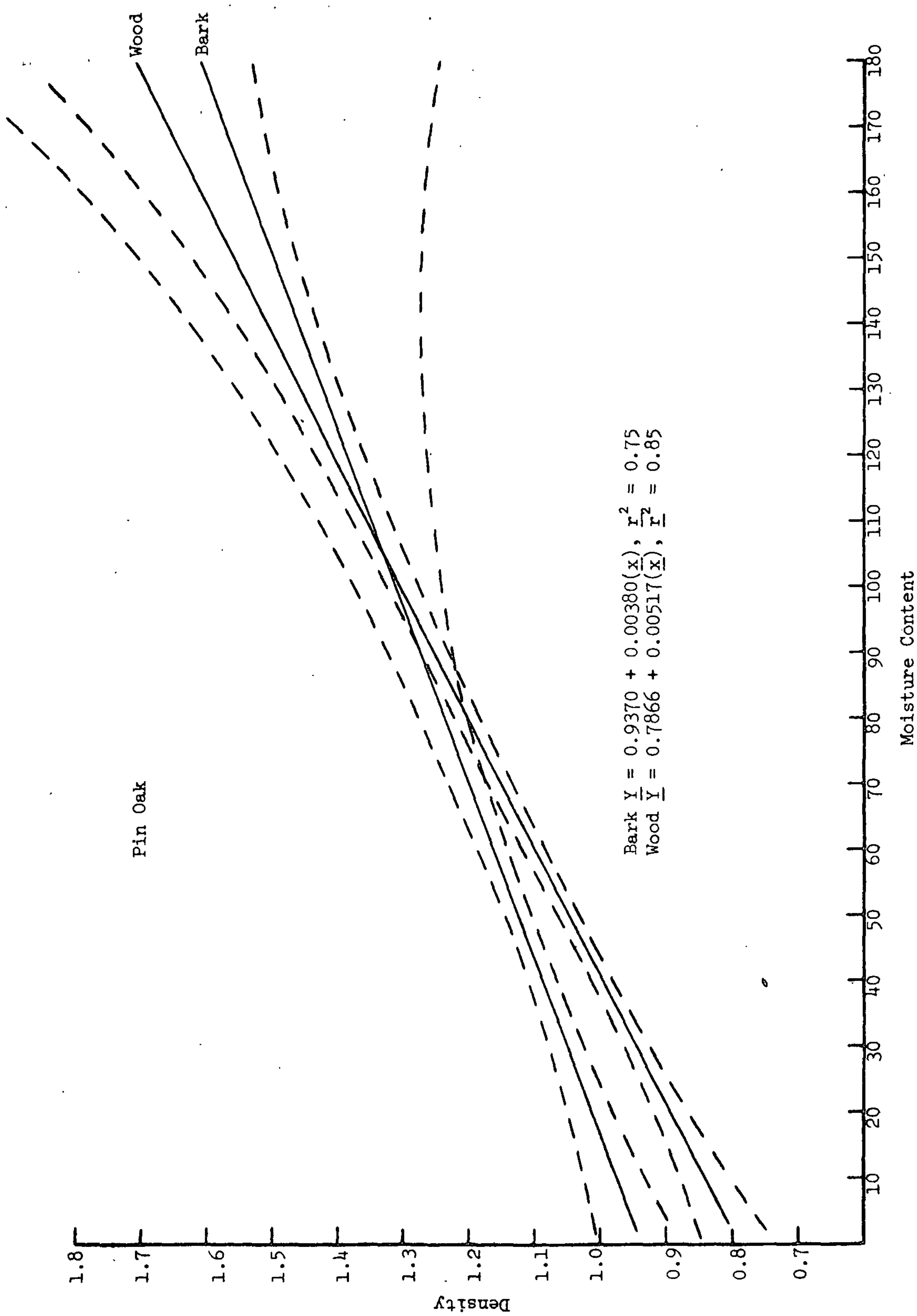


Figure 16. Illustrated Is the Relationship Between Basic Density and Moisture Content for Pin Oak. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XVIII summarizes the results for pin oak. At moisture content ranges covered by the wood and bark chips (69 to 76%), both fractions should sink according to the density-moisture content curves. Most chips did sink, leaving only a small percentage floating.

DATA INTERPRETATION

The high extractives present in the bark of pin oak (14.9%) might make it desirable in some instances to remove as much of the bark as possible from a wood/bark chip mixture. Hammermilling experiments gave intermediate results with 33% of the bark removed and a wood loss of 6% when the material on the 14-mesh screen was retained. The amount of bark removed could be increased to 46% by retaining only the material on the 10-mesh screen but the wood loss would also increase to 9%. Segregation through water flotation would not be a feasible technique as the wood and bark are too close in density at similar moisture contents. Again, it is possible that a quick segregation could be made by screening the chips, hammermilling the fractions high in bark and rescreening.

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR PIN OAK

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-127 Bark	69.3	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-127 Exterior wood	76.5	after 5	91.8	8.2
		15	91.8	8.2
		60	91.8	8.2
		240	97.3	2.7
IPC 3212-127 Interior wood	77.1	after 5	99.0	1.0
		15	99.0	1.0
		60	99.0	1.0
		240	100	0
IPC 3212-130 Bark	69.5	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-130 Sapwood	74.9	after 5	97.4	2.6
		15	97.4	2.6
		60	97.4	2.6
		240	97.4	2.6
IPC 3212-130 Heartwood	70.8	after 5	97.4	2.6
		15	97.4	2.6
		60	97.4	2.6
		240	97.4	2.6

Pin oak bark does contain some fiber. Bark micropulping results indicate screening the pulp would remove most of the sclereids and result in 2% usable fiber.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (13), Hooper (14), Biltonen, *et al.* (15), Short, *et al.* (16), Miller (17) and Vais and Vostrov (18). A paper by Barker (22) deals with the papermaking properties of young hardwoods, including an oak.

BARK AND WOOD PROPERTIES OF BLACK OAK
[*Quercus velutina* Lam.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Found in nearly all upland hardwood forest types, black oak also occurs in some pine types east of the Great Plains. It is found from southeastern Minnesota east to southern Maine. It is also found through the South to northwestern Florida, and along the Gulf Coast. The tree is found west into eastern Texas, Oklahoma, Kansas, southeastern Nebraska, and in all but northwestern Iowa. Black oak grows on drier sites than white and northern red oaks, but does not thrive where post and blackjack oak commonly grow. It is found on dry, sandy or rocky ridges; on upper slopes or on heavy, glaciated, clay hillsides. However, it grows best on lower slopes and coves in unglaciated regions. Although most mature trees are from 60 to 80 feet tall and 2 to 3 feet in diameter, black oak may reach 150 feet in height and 4 feet in diameter on the best sites. Some individuals may reach 150 to 200 years of age, although it becomes physiologically mature at about 100 years of age. The stumps of young trees of this species also sprout freely and young trees tend to develop a long taproot which helps them survive on dry sites.

WOOD AND BARK MORPHOLOGY

Wood

The woods of the various red oaks cannot be separated from each other with certainty and the description that follows applies to black oak as well as pin oak. In general, the wood is hard and heavy. The heartwood appears pinkish to pale reddish brown, while the sapwood is whitish to grayish or light reddish brown. A ring-porous wood, the growth rings are very distinct and earlywood (springwood) pores are large, forming a conspicuous band 1-4 pores in width. The transition to latewood (summerwood) is gradual to more or less abrupt, and the pores are more abundant, round, small, thick-walled and less distinct. The largest vessels are 200-430 µm in diameter in the earlywood and number 10-30 per sq mm in the latewood. Rays, also conspicuous to the naked eye, are unstoried, homogeneous, and of two types. The broad rays are approximately 12-30 seriate and 150-400+ µm in diameter. On a tangential surface, these broad rays are separated by numerous narrow rays, usually uniseriate and very variable in height, 1-20+ cells. Paratracheal parenchyma intermingle with tracheids, forming part of the conjunctive tissue between the earlywood pores and the rays, and composing most of the light-colored tissue in the latewood vessel area. Very abundant, the parenchyma are usually metatracheal or metatracheal-diffuse, usually zonate in fine, more or less regular, tangential lines in the outer portion on the ring. Red oak fibers, medium to thick-walled, measure 14-22 µm in diameter and average 1.4 mm in length.

Bark

The bark is thick and nearly black on old trunks and deeply divided into broad, rounded ridges. The inner bark is thick, yellow and very bitter to the taste. The inner bark for the trees examined averaged 54%. Figure 17 illustrates a cross section of the wood and inner bark of black oak. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

Sclerenchyma in the inner bark of the sample examined occurred very close to the cambium zone in the form of fibers with very few sclereids in this region. The fibers were clustered in interrupted, tangential bands. The proportion of sclereid cells increased noticeably toward the outer zones of the inner bark and, at the innermost periderm, were present in very large masses. Many sclereids were crystalliferous. Most sieve tubes in the inner bark were crushed.

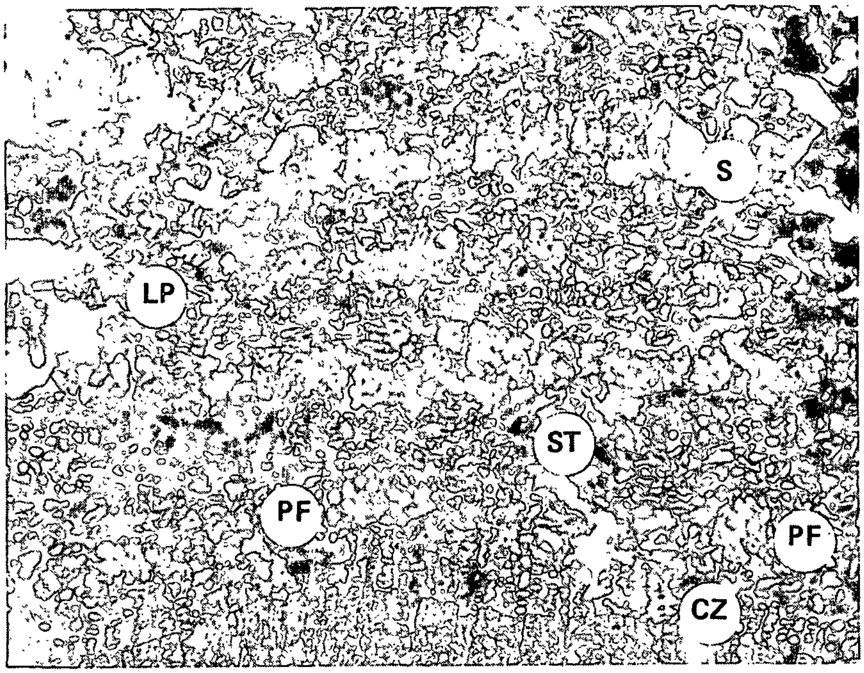


Figure 17. Cross Section of the Wood and Inner Bark of Black Oak. Shown Is the Cambium Zone (CZ), Phloem Fibers (PF), Sieve Tubes (ST), Longitudinal Parenchyma (LP) and Sclereids (S). Magnification — 75X

Both large and small rays were present and crystalliferous ray, as well as longitudinal, parenchyma were common. As the larger rays approached the outer bark, they became somewhat dilated and essentially all sclerotic. However, even near the cambium zone, the large rays contained numerous sclerotic parenchyma. The cambium zone of the large rays also projected toward the pith, and this ray feature, together with their phloem portion being largely sclerotic, probably promoted the characteristic ray pullout of the wood/bark adhesion samples.

The outer bark was similar to that of the other oaks.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIX summarizes the information available on wood and bark of black oak. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of black oak at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.57 appears appropriate for the wood of black oak. Our samples were divided into sapwood and heartwood and specific gravity determinations made on each. Our limited data showed the heartwood and sapwood to be close in specific gravity.

The specific gravity of the total (inner + outer) bark of black oak is somewhat higher than that of the wood, using the average of four determinations. The outer bark was higher in specific gravity than the inner bark in two of four

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

total determinations but lower in the others. Using averages, overall values suggested for use in species comparisons are 0.57 for wood and 0.69, 0.68 and 0.68 for inner, outer and total bark. Black oak, also a member of the red oak group, has specific gravities similar to other species in that group.

TABLE XIX

BLACK OAK SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References and Remarks
	0.80	0.82		Fournier and Goulet (24)
0.62			0.61	Manwiller (4)
0.58 (cores)				Maeglin (5)
0.58				Bendtsen and Ethington (6)
0.51 (sapwood) 0.50 (heartwood)	0.72	0.64	0.73	IPC 3212-119
0.58 (exterior) 0.63 (interior)	0.61	0.39	0.56	IPC 3212-132
0.49 (sapwood) 0.48 (heartwood)	0.62	0.86	0.81	IPC 3212-133

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

No information was found in the literature on alcohol-benzene extractives and the table includes only IPC information. Table XX summarizes these measurements. Black oak wood is fairly low in extractives and a level of 5.0% is suggested for use in between-species comparisons. Extractives work done on black oak bark in this project showed an average level of 15.4%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE XX

BLACK OAK EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	3.3	IPC 3212-119
Wood	3.1	IPC 3212-132
Wood	8.7	IPC 3212-133
Bark	13.8	IPC 3212-133
Bark	16.2	IPC 3212-132
Bark	16.3	IPC 3212-119

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped black oak bark.

The short, thin-walled sieve tubes (see photomicrographs) are also often present in considerable numbers in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, most of the sclereids in the pulped black oak bark went through the 150-mesh screen and would not be a factor in the usable pulp.

As a check on pulp yield and the nature of the material produced from black oak, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXI summarizes the results of this investigation. Micropulping

TABLE XXI

BLACK OAK MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-119	Sample No. 3212-132	Remarks[a]
Yield, % solids	28.7	34.0	
Fraction			
On 60 mesh, %	14.9	10.0	The furnish of the fraction contained principally phloem fibers (95+%) and a small percentage (<5%) of sieve tubes. Average arithmetic length of the phloem fibers was 1.20 mm
On 100 mesh, %	4.1	4.7	The fraction contained mainly phloem fibers (95+%) with a small percentage of sieve tubes (<5%)
On 150 mesh, %	1.8	1.1	The fraction contained a large percentage of phloem fibers (50-60%) with smaller percentages of sieve tubes (25-35%), crystalliferous parenchyma (<10%), parenchymatous cells (<5%), and a trace of sclereids
On 200 mesh, %	1.1	1.4	The fraction contained a large percentage of sieve tubes (50-60%) with a smaller percentage of phloem fibers (15-25%), sclereids (10-20%), parenchymatous cells (<10%) and a trace of crystalliferous parenchyma
Through 200 mesh, %	78.1	82.8	The fraction contained a large percentage of parenchymatous and thin-walled peridermal cells (40-50%), with smaller percentages of sclereids (30-40%), sieve tubes (5-15%), and crystalliferous parenchyma (5-15%).

[a]Percentages given are on a dry weight basis.

black oak bark resulted in a yield of 28 to 34% solids. When screened, the coarse screens (60 and 100 mesh) retained mostly phloem fibers. The on 150-mesh screen also contained many phloem fibers plus sieve tubes and parenchyma. The on 200-mesh and through 200-mesh screens had large percentages of sieve tubes and parenchymatous and peridermal cells along with smaller amounts of sclereids. Figure 18 illustrates the type of material retained on the 60- and 150-mesh screens.

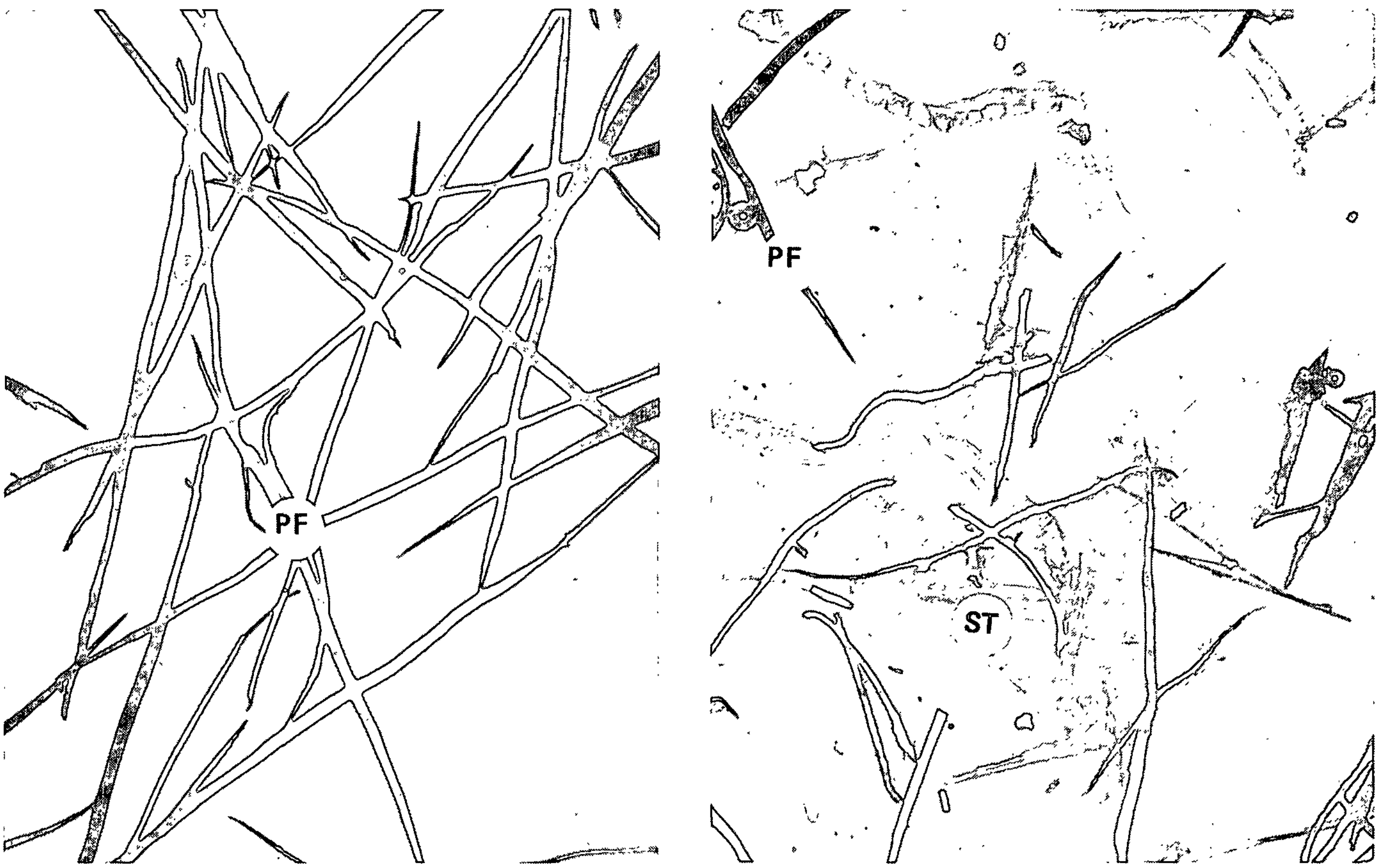


Figure 18. The 60-Mesh Screen (Left) Contained by Weight Principally Phloem Fibers (95+%). The 150-Mesh Screen (Right) Contained a Large Percentage of Phloem Fibers (50-60%) with Smaller Percentages of Sieve Tubes (25-35%). Magnification — 75X. Symbols Illustrate Phloem Fibers (PF) and Sieve Tubes (ST)

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 31 grams of solids will result. Of this 31 grams, about 5.0 grams (5.0%) of phloem fibers and 0.3 gram (0.3%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations. The amount of fiber retained on the 60- and 100-mesh screens was slightly higher than that retained for other oaks investigated in this project.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study has been to obtain growing season and dormant season information on (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for black oak samples collected February 24 and March 30. After testing, the dormant season samples were examined to determine the location of the zone of failure. Figure 19 illustrates the zone of failure for black oak during the dormant season. Wood/bark adhesion values averaged 21.5 kg/cm^2. Failure zones varied considerably on the examined sample from the cambium zone outward to 1 mm into the phloem. The latter failure zones seemed to be associated with tangentially arranged clusters of phloem fibers, which were both gelatinous and nongelatinous. Many crystalliferous parenchyma cells were also seen to be associated around and within these sclerenchyma groups. Xylary ray pullout was characteristic of the large rays and was associated with inwardly directed masses or spearheads of sclerotic ray parenchyma which were largely retained on the phloem side of the test specimen.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. In the oaks, sycamore and beech, xylary rays may also contribute to higher adhesion values, especially where sclerenchyma in the rays are lignified into the cambium zone. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the

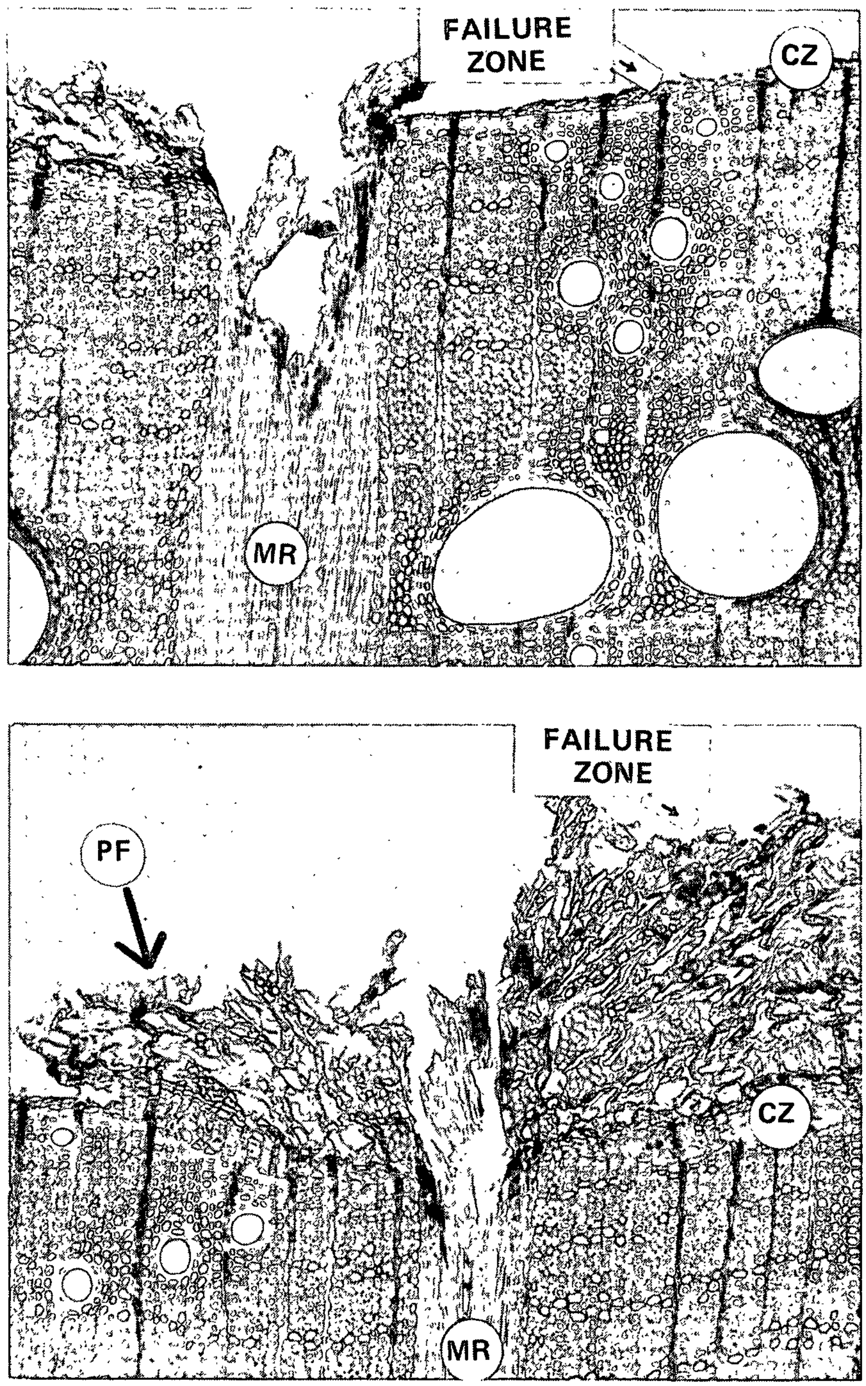


Figure 19. Illustrated Are the Failure Zones for Black Oak During the Dormant Season. Failure in the Top Photomicrograph Occurred in the Cambium Zone While the Bottom Photomicrograph Shows the Failure Occurring in the Phloem, Which Is More Typical of Dormant Season Failure. Both Photomicrographs Illustrate the Ray Pull-out Which Is Characteristic of the Oaks. Magnification — 75X. Symbols Illustrate Multiseriate Rays (MR), Cambium Zone (CZ), Phloem Fibers (PF)

differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of black oak. (Appendix Tables XXXIX and XL compare the modulus of elasticity of black oak with other species examined in this project.)

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF BLACK OAK[a]

Material	Strength	Toughness
Wood	--	0.86
Inner bark	11.7	0.29
Outer bark	9.7	0.10

[a]Determinations average of two trees, except inner bark strength which is based on three trees.

Bark strength values for black oak inner and outer bark were both quite high. Toughness values for both the wood and inner bark were also high while the outer bark was intermediate in toughness. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Since toughness and strength measurements are high, it appears that hammermilling or a similar mechanical action might not work as well on this species as it did on southern red oak, although both are members of the red oak group, since southern red oak had lower toughness and strength values but similar bark specific gravity.

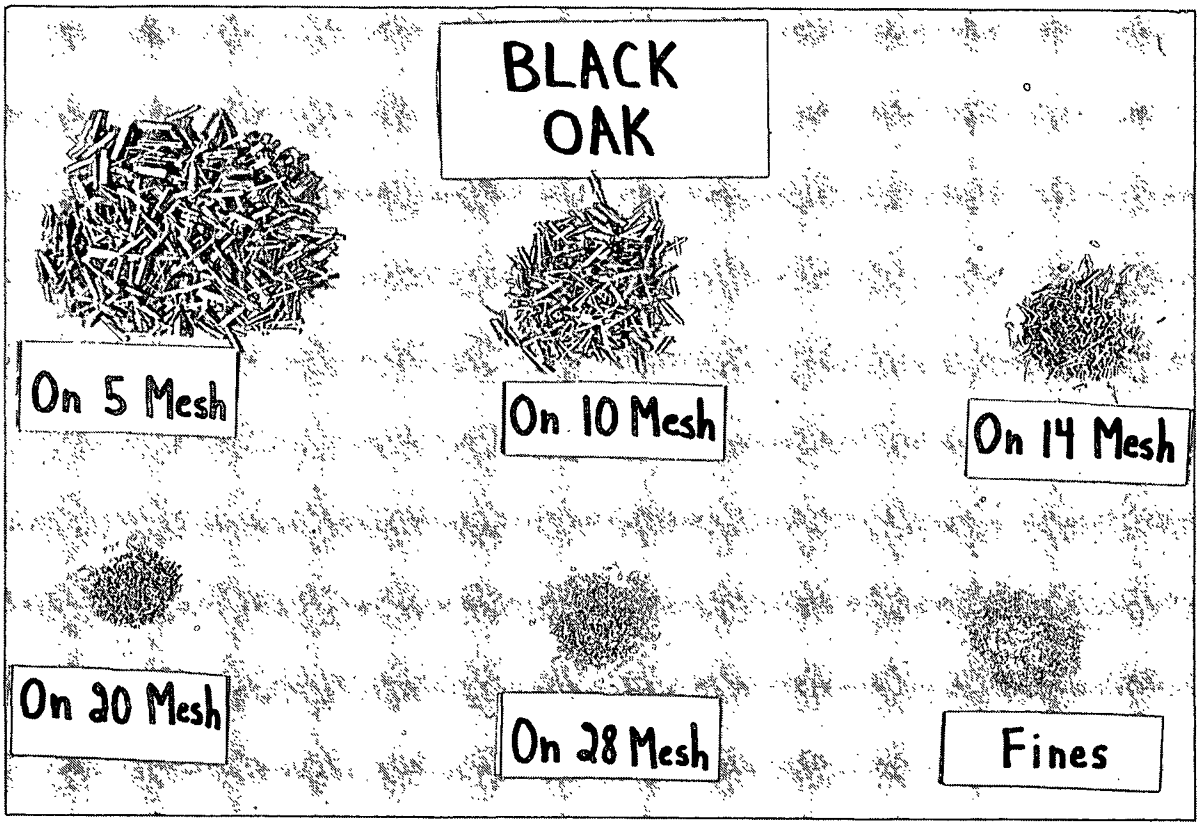
Summarized in Table XXIII are the results of the hammermilling tests run on black oak wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a moderate reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 7% wood loss and a 37% reduction in levels of bark. As predicted by the toughness and strength measurements, bark removal was less than obtained for southern red oak (see Table XXXIV). A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (50% bark removal and 11% wood loss). Since black oak bark contains fiber, the increased wood loss may not justify the additional bark removal. Figure 20 illustrates the effect of hammermilling on wood and bark of black oak. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON BLACK OAK

Tree No.	Material	Fraction Retained on Standard Screen[a], %						Remarks
		5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	
3212-119	Bark	22.8	23.5	15.0	5.8	13.1	19.8	2/3+ Inner bark on larger mesh screens; increasing amounts of outer bark on smaller mesh screens
	Sapwood	73.6	14.7	3.3	2.4	2.2	3.8	
	Heartwood	68.8	16.9	4.2	1.6	2.6	6.0	
3212-132	Bark	36.3	17.9	11.1	5.7	7.6	21.1	Same as above
	Exterior wood	83.4	7.7	2.3	1.6	1.5	3.5	
	Interior wood	83.1	9.5	2.6	1.3	1.3	2.1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.



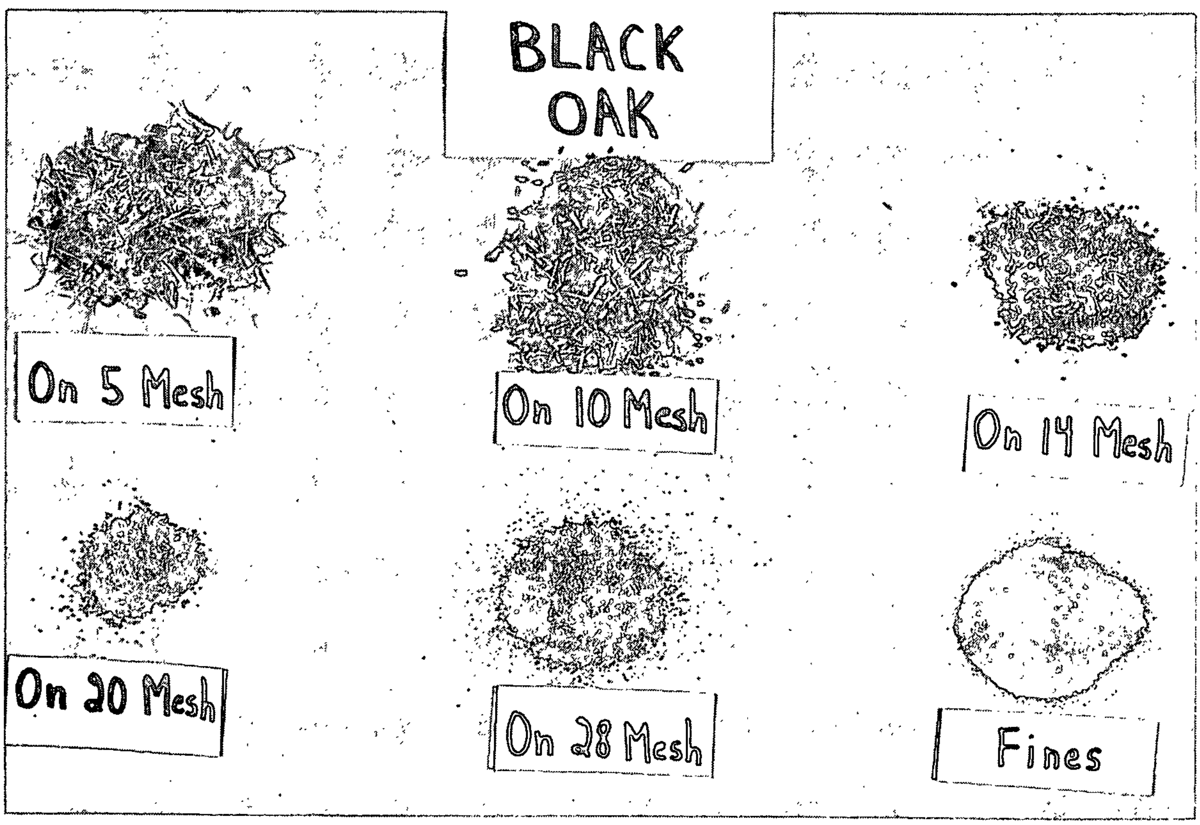


Figure 20. Illustrated Is the Effect of Hammermilling on Black Oak Wood (Top) and Bark (Bottom)

bark could be treated by some other method or used for fuel. It is also possible improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 20 (25-27). This would apply to outer bark only, which was in rounder pieces after hammermilling, rather than inner bark which, due to the fiber it contains, is long and stringy. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of black oak with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two black oak trees (IPC 3212-119 and IPC 3212-132) were used in making the determination. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark for 3212-119 were all fairly close in density at various moisture contents. However, for 3212-132, the inner bark had a greater density at various moisture contents than the total bark.

Figures 21 and 22 illustrate the relationship that was found between moisture content and density. The linear relationships shown were obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

Separate curves had to be established for the two trees investigated. When the data for the two trees were combined, the r^2 value for bark was only 0.26, indicating differences in density at the same moisture content. Plotted separately, r^2 values for bark were 0.72 and 0.91 for 3212-119 and 3212-132, respectively.

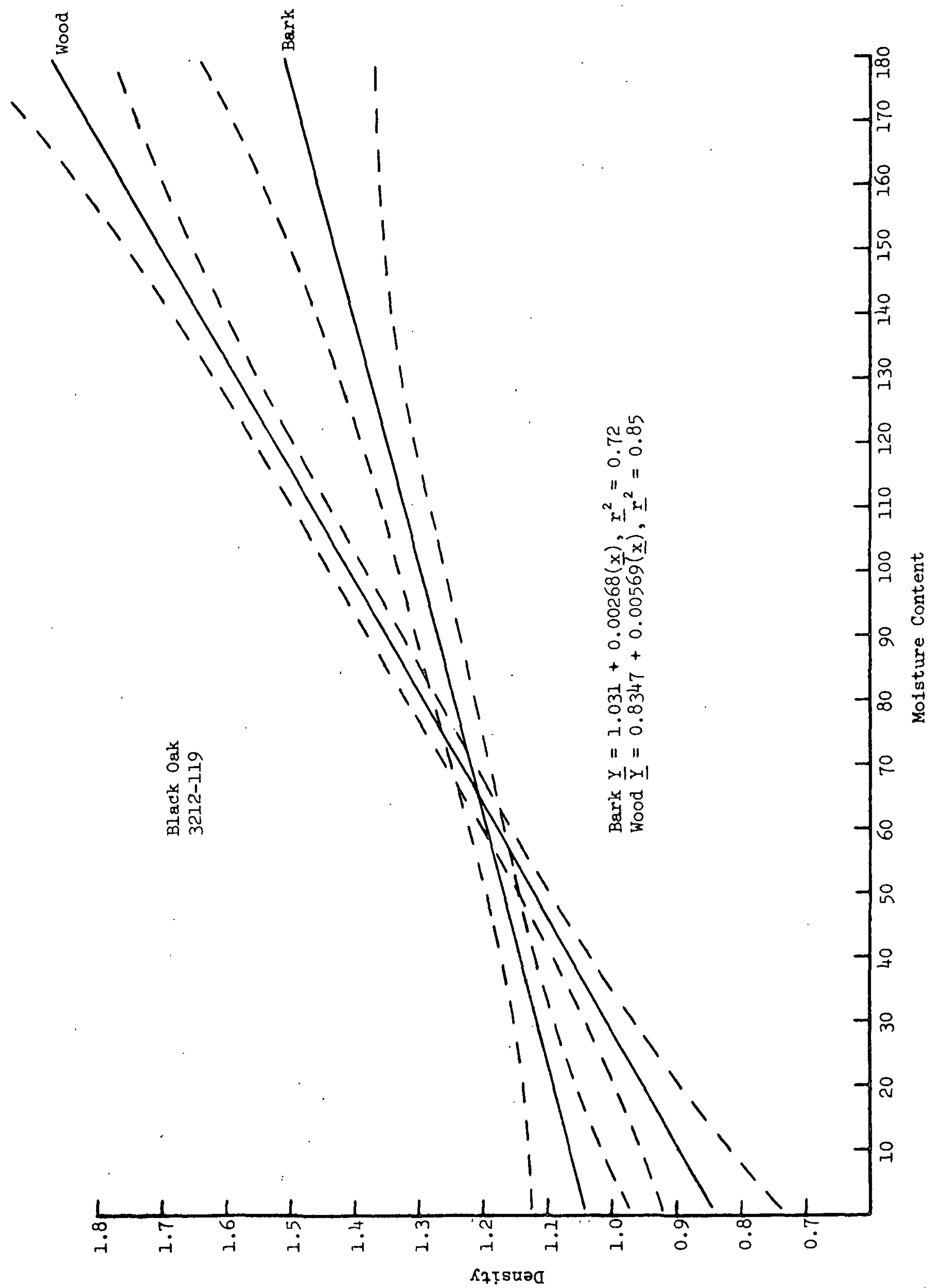


Figure 21. Illustrated Is the Relationship Between Basic Density and Moisture Content for One of the Black Oak Trees Examined. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

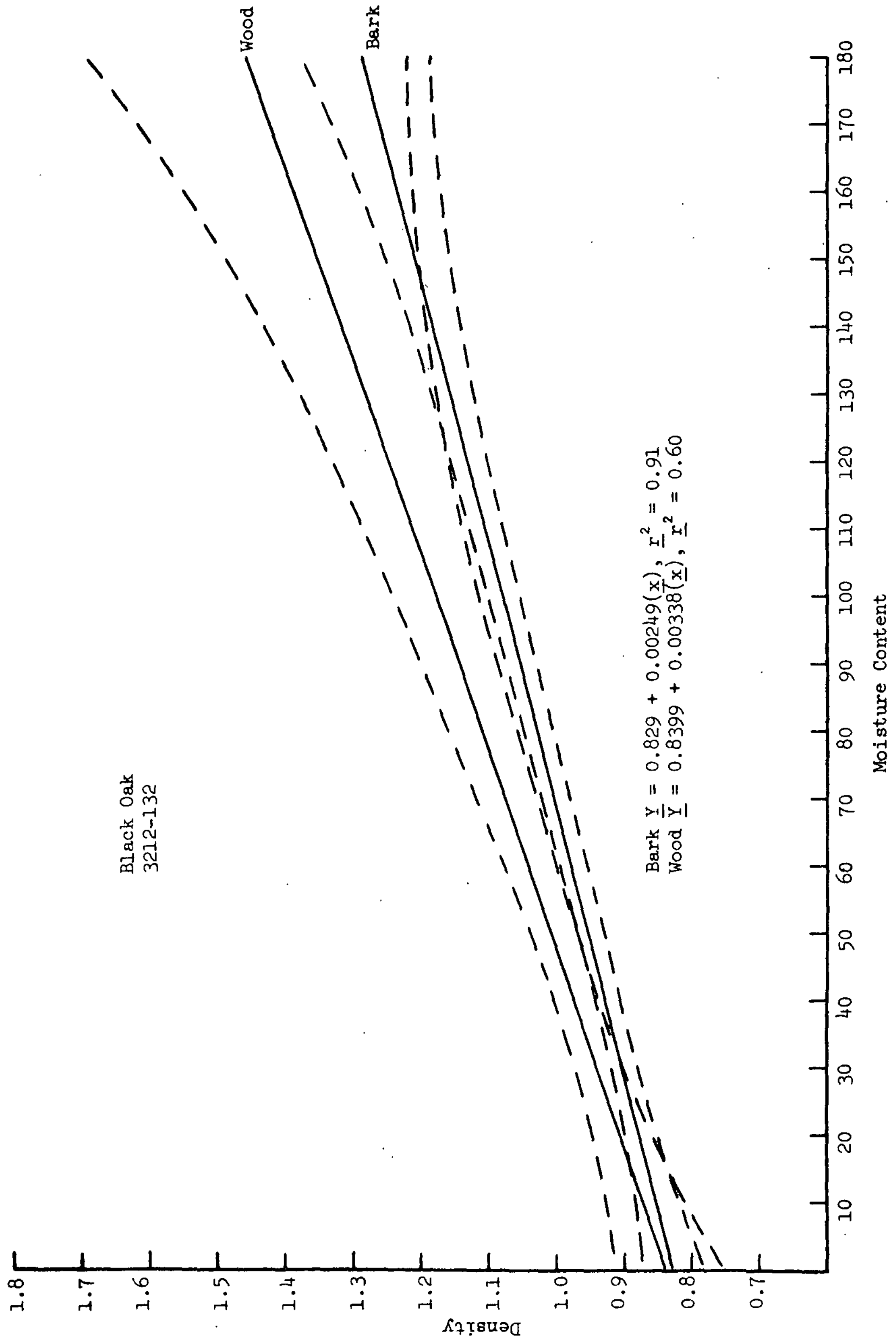


Figure 22. Illustrated Is the Relationship Between Basic Density and Moisture Content for the Other Black Oak Tree Examined. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

However, both curves show that segregation through water flotation would not be possible for black oak wood and bark chips. At lower moisture contents, wood and bark chips are too close in density and both would sink at higher moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XXIV summarizes the results for black oak. The chips for both trees behaved as expected from the density-moisture content curves. At moisture contents above approximately 35%, both wood and bark should sink for 3212-119 and this is essentially what happened. It would require moisture contents of about 70% or above for most wood and bark chips of 3212-132 to sink. Since the moisture content of the wood from that tree had been equilibrated close to that point, it is reasonable to expect more of it to float.

TABLE XXIV

SUMMARY OF DWELL TIME RESULTS FOR BLACK OAK

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-119 Bark	65.4	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-119 Sapwood	64.6	after 5	95.6	4.4
		15	95.6	4.4
		60	95.6	4.4
		240	95.6	4.4
IPC 3212-119 Heartwood	73.4	after 5	92.6	7.4
		15	92.6	7.4
		60	94.5	5.5
		240	97.6	2.4
IPC 3212-132 Bark	115.7	after 5	95.2	4.8
		15	95.2	4.8
		60	95.2	4.8
		240	98.5	1.5
IPC 3212-132 Exterior wood	76.1	after 5	79.2	20.8
		15	79.2	20.8
		60	87.8	12.2
		240	92.3	7.7
IPC 3212-132 Interior wood	72.9	after 5	92.1	7.9
		15	92.1	7.9
		60	92.1	7.9
		240	93.2	6.8

DATA INTERPRETATION

Black oak, which is a member of the red oak group, as is pin oak, also has high bark extractives levels (15.4%). This may make it desirable to remove at least part of the bark from a wood/bark chip mixture. Dwell time and density vs. moisture content information indicate that segregation through water flotation would not work with this species. Densities of wood and bark are too close at low moisture contents and both fractions would sink at higher moisture contents.

Hammermilling wood and bark chips resulted in a 7% wood loss and a 37% reduction in levels of bark if the material on the 14-mesh and larger screens was retained. If only the material on the 10-mesh and larger screens was retained, the result would be an 11% wood loss and a 50% reduction in bark levels. This rather large wood loss may not be justified by increased bark removal unless the material removed has considerable value as fuel. However, it appears that the bark could be concentrated into one or two small-sized chip fractions by screening and those fractions hammermilled and rescreened. This would probably remove a good share of the outer bark which is in round pieces rather than stringy like the inner bark. The round shape of the outer bark would cause it to fall through the screens more readily.

Another alternative would be to pulp the bark. Bark micropulping results indicate screening the pulp would remove most of the sclereids and result in 5% usable fiber.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (13), Hooper (14), Biltonen, *et al*. (15), Short, *et al*. (16), Miller (17) and Vais and Vostrov (18). A paper by Manwiller (19) examines wood and bark moisture contents of small-diameter hardwoods while one by Koch (28) contains information on bark volume of black oak.

BARK AND WOOD PROPERTIES OF AMERICAN BEECH
(*Fagus grandifolia* Ehrh.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

American beech, the only species of this genus in the United States, is confined to the Eastern United States. It is found from Nova Scotia to northern Michigan and eastern Wisconsin in the north, to northwestern Florida and eastern Texas in the south. Within this range the growing season varies from 100-280 days and annual precipitation, from 30-50 inches. As a mesophytic species, beech prefers loamy textured solids and those with a high humus content over lighter soils, and will grow on poorly drained sites not subjected to prolonged flooding. The species grows at elevations up to 6000 ft; however, over most of the range, it is more abundant on the cooler, moister northern slopes than on the southern slopes. The largest trees are found in the alluvial bottom lands of the Ohio and the lower Mississippi River valleys and along the western slopes of the southern Appalachian Mountains. Averaging 60-80 ft high, trees may reach a height of 120 ft under optimum conditions. Beech trees begin seed production at about 40 years of age, sprout well from stumps less than 4 inches in diameter, and may develop root suckers. However, in forest stands with associated hardwood species, heavy cutting tends to reduce beech reproduction and repeated clear cutting on short rotation may nearly eliminate the species.

WOOD AND BARK MORPHOLOGY

Wood

American beech is a diffuse porous wood with distinct growth rings delineated by a dark line or band of denser latewood. The indistinct small pores are usually crowded and largest in the earlywood, decreasing in size and number, to very small in the latewood. The wood is heavy (sp. gr. approximately 0.56 green, 0.67 ovendry), with a whitish sapwood and reddish-tinged heartwood. Broad (oak type) rays, plainly visible, are separated by several narrow fine rays. Occupying about 20.4% of the total wood volume, both ray types are unstoried and homogeneous or with marginal upright cells. The broad rays are 12-25+ seriate and one to several millimeters in height along the grain. The numerous narrow rays are 1-5 seriate and up to 500+ µm in height. Parenchyma are abundant, metatracheal, and metatracheal-diffuse. Vessels, numbering 50-200 per sq mm are approximately 0.6 mm in length, the largest 60-90 µm in diameter. Thick-walled fibers average 1.3 mm (range 0.6-1.9 mm) in length and 16-22 µm in diameter.

Bark

The bark of American beech is similar in appearance on both old and young trunks. It is thin, close, smooth, light blue-gray and often mottled. The inner bark for the trees examined averaged 83% by weight. Figures 23 and 24 illustrate a cross section of the wood, inner and outer bark of American beech. Appendix Table XXXVI describes the trees used in this study.

Anatomical Structure of Bark

Near the cambial zone (CZ), the inner bark consists of alternating tangential bands of longitudinal parenchyma (LP) and sieve-tube elements. The latter are of ten crushed. The small phloem rays are apparently not lignified and are distorted somewhat as they project outwardly into the older phloem. The larger multiseriate rays are not distorted, apparently are lignified, and show sclerosis just outside the cambium zone. These ray cells are also crystalliferous. The longitudinal parenchyma also tend to become more crystalliferous in older phloem.

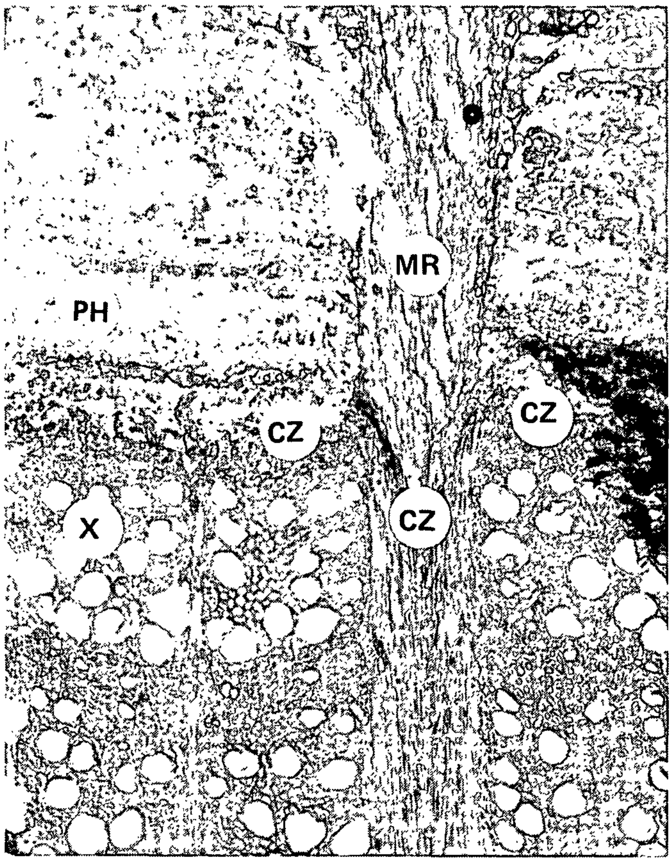


Figure 23. Cross Section of the Wood and Inner Bark of American Beech. Illustrated Is the Xylem (X), Cambium Zone (CZ), Phloem (PH) and Multiseriate Ray (MR). Magnification — 75X

An interesting feature of the large multiseriate rays in beech is that the cambium zones of the rays themselves project inwardly from what would be considered their normal position. The latter would normally be expected to consist of a circumferential zone of cells in line with the cambium zone of the nonray tissue. It is apparent, however, that in hardwoods with "oak-type" rays, the cambium zone of these large rays is displaced inward toward the pith in a V-shaped wedge. It is probably this situation that causes the apparent xylem portion of such rays to pull out with the phloem tissue in many of the oaks tested for wood/bark adhesion.

An additional contributing factor to the above phenomenon may be the frequent existence in these large multiseriate rays of sclerotic parenchyma and/or crystalliferous parenchyma just outside their cambium zone in the recent phloem ray derivatives. In any case, the ray pullout observed in beech and oak actually results from failure in the cambium zone of these large rays and not failure in the true xylary portion of such rays.

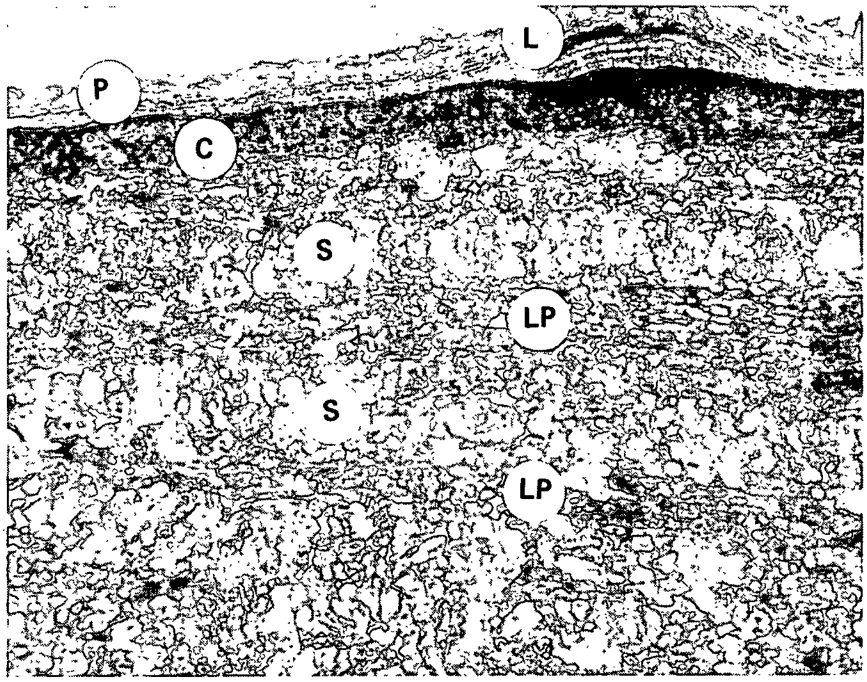


Figure 24. Cross Section of American Beech Inner and Outer Bark. Shown Are Longitudinal Parenchyma (LP), Sclereids (S), Collenchyma (C), Periderm (P), and Lenticol (L). Magnification — 75X

Inner bark nonray and ray sclerenchyma cells were relatively rare near the cambium zone but became more numerous toward the periderm. Larger and more frequent clusters of fibers and/or sclereids (often also crystalliferous) alternate with tangential bands of longitudinal parenchyma and crushed sieve tubes near the outer bark. These clusters contain mostly sclereids rather than fibers closer to the outer bark.

The outer bark appears to consist of only one periderm but with concentric, alternating layers of thin and thick-walled phellem cells, except in lenticel regions. Just beneath the phellegen area, there appears to be only a few, if any, distinguishable phelloderm cells, and cortical parenchyma (colenchyma) are persistent in many locations. No true sclereids or fibers were observed in the outer bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XXV summarizes the information available on wood and bark of American beech. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of American beech at several moisture contents.

An average specific gravity (ovendry weight/green volume) of approximately 0.60 appears appropriate for the wood of American beech. Our samples were divided into sapwood and heartwood and specific gravity determinations made on each. Our limited data showed the heartwood and sapwood to be very close in specific gravity.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

TABLE XXV

AMERICAN BEECH SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Average	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.55 (cores)				U.S. For. Prod. Lab. (23)
			0.53	Fournier and Goulet (24)
0.56				Isenberg (29)
0.56				IUFRO
0.57 (sapwood) 0.61 (heartwood)	0.69		0.75	IPC 3212-123
0.66 (sapwood) 0.65 (heartwood)	0.64		0.67	IPC 3212-129
0.63 (sapwood) 0.63 (heartwood)	0.67		0.72	IPC 3212-134

The specific gravity of the total (inner + outer) bark of American beech is slightly higher than that of the wood. No comparisons could be made between inner and outer bark as the outer bark was too thin for specific gravity measurements. Overall values suggested for use in species comparisons are 0.60 for wood and 0.67 for both inner and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists in the literature on alcohol-benzene extractives levels of American beech wood. Table XXVI summarizes existing data and includes the three IPC trees examined. American beech wood is low in extractives and a level of 1.5% is suggested for use in between-species comparisons. Extractives work done on American beech bark in this project showed an average level of 10.6%. This is an intermediate level and extractives are not expected to be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE XXVI

AMERICAN BEECH EXTRACTIVES

Type of Material	Extractives, %	Sources
Sapwood	0.20	Fengel and Grosser (30)
Heartwood	0.57	Fengel and Grosser (30)
Wood	1.0-1.4	Rydholm (31)
Wood	1.8	Isenberg (29)
Wood	1.4	IPC 3212-123
Wood	1.7	IPC 3212-129
Wood	1.4	IPC 3212-134
Bark	9.0	Murphy, et al. (32)
Bark	10.9	IPC 3212-123
Bark	12.6	IPC 3212-129
Bark	9.7	IPC 3212-134

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Some phloem fibers are found in American beech but not in the quantities described for shagbark hickory and the oaks.

The short, thin-walled sieve tubes (see photomicrographs) are also often present in bark pulps and could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, most of the sclereids in the IPC pulped samples passed through the 200-mesh screen where they would have no effect on the pulp produced.

As a check on pulp yield and the nature of the material produced from American beech, 20- to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXVII summarizes the results of this investigation. Micropulping American beech bark resulted in a yield of 36 to 38% solids. When screened, the coarse screens (60 and 100 mesh) retained phloem fibers, sieve tubes and some parenchymatous cells. However, only between 1.4 and 2.3% of the total amount of solids was retained on these two screens. The on 150-mesh screen contained principally sieve tubes along with some parenchymatous cells. The on 200-mesh and through 200-mesh screens contained large amounts of sieve tubes and sclereids with some parenchymatous cells. The material passing through the 200-mesh screen averaged 93.4%. From these results, it seems likely that only a small amount of bark would remain in the pulp even if all the bark was pulped with the wood. Figure 25 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 37 grams of solids will result. Of this 37 grams about 0.25 gram (0.25%) of fiber and 0.35 gram (0.35%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material, including most of the sclereids, would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and

TABLE XXVII

AMERICAN BEECH MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-129	Sample No. 3212-134	Remarks[a]
Yield, % solids	36.3	37.7	
Fraction			
On 60 mesh, %	1.1	0.7	The fraction contained roughly 50% each of phloem fibers and sieve tubes
On 100 mesh, %	1.2	0.7	The fraction contained a large percentage of sieve tubes (55-65%), with smaller percentages of parenchymatous cells (25-35%), phloem fiber (<10%) and a trace of sclereids. Average arithmetic length of the sieve tubes was 0.64 mm
On 150 mesh, %	3.2	2.2	The fraction contained a large percentage of sieve tubes (75-85%), a small percentage of parenchymatous cells (10-20%) and traces of phloem fibers and sclereids
On 200 mesh, %	1.8	2.2	The fraction contained a large percentage of sieve tubes (75-85%) with smaller percentages of parenchymatous cells (15-25%) and sclereids (<5%)
Through 200 mesh, %	92.7	94.2	The fraction contained a large percentage of sclereids (65-75%) with smaller percentages of parenchymatous cells (15-25%) and sieve tubes (5-15%)

[a]Percentages given are on a dry weight basis.

dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

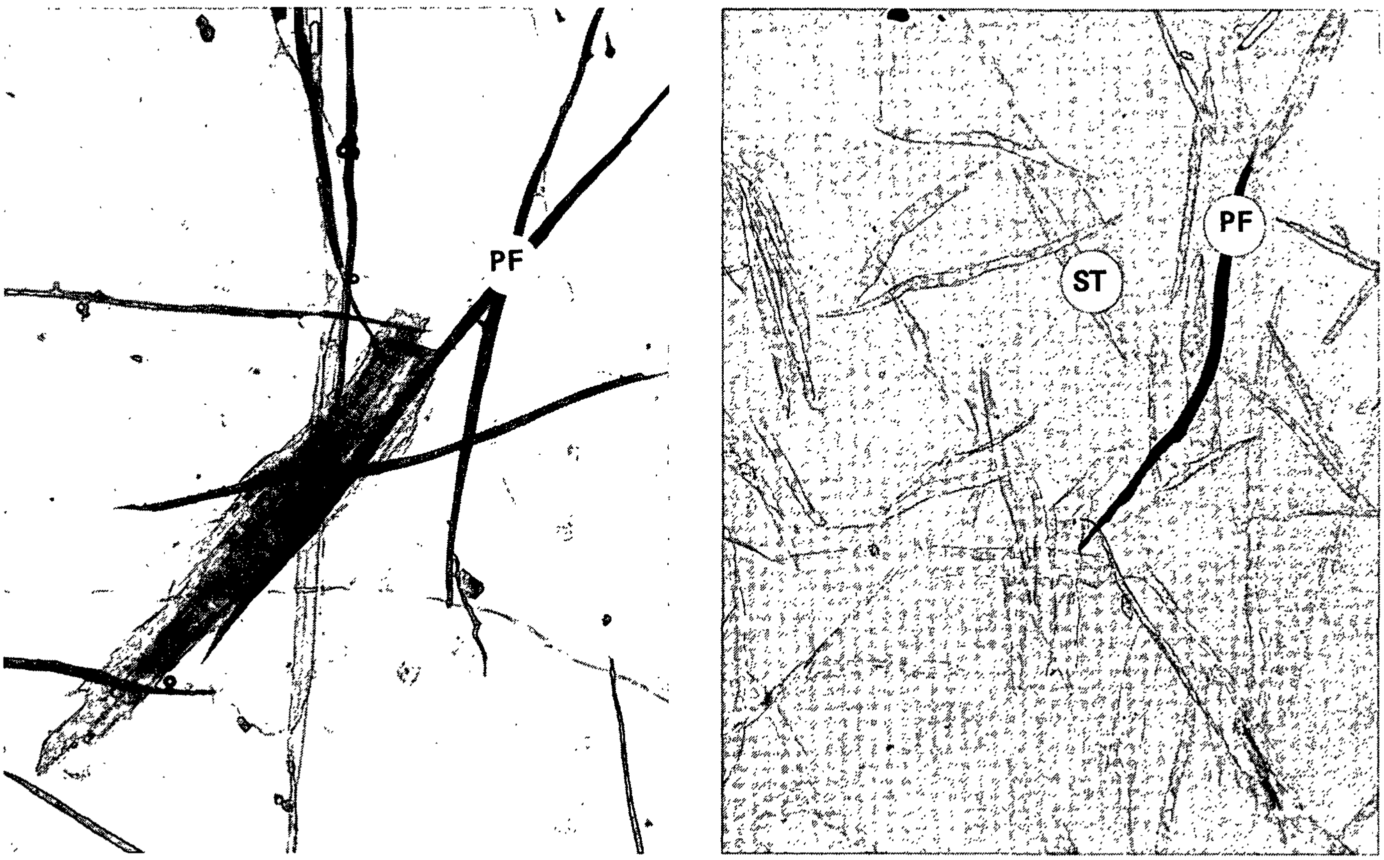


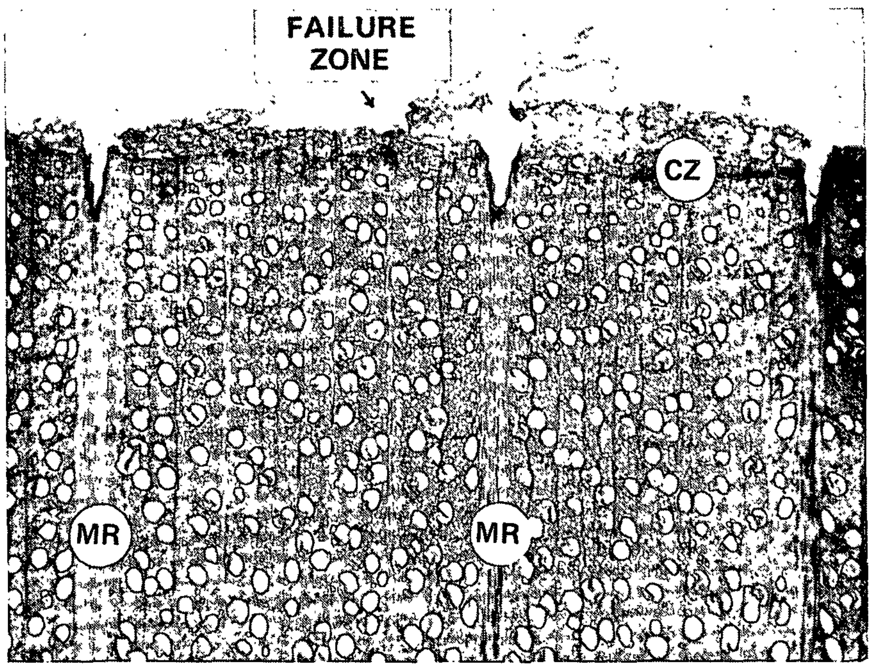
Figure 25. The 60-Mesh Screen (Left) Contained by Weight Approximately 50% Each of Phloem Fibers (PF) and Sieve Tubes (ST). The 150-Mesh Screen (Right) Contained a Large Percentage of Sieve Tubes and a Trace of Phloem Fibers. Magnification — 75X

Using the sampling and testing procedures described in the section on Experimental Procedures, shear parallel to the grain was measured for appropriately collected samples. Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6

kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly-formed xylem elements just outside the cambium zone.

Dormant season wood/bark adhesion values were measured for American beech samples collected March 10 and 20. After testing, the dormant season samples were examined to determine the location of the zone of failure. Figure 26 illustrates the zones of failure for American beech during the dormant season. Wood/bark adhesion values averaged 14.0 kg/cm^2. The failure zone on the examined sample took the form of an irregular tangential line, extending into the phloem generally for about 0.1-0.2 mm. However, several failure areas were in the cambium zone itself with other areas extending outward into the phloem as much as 0.5 mm. Phloem failure occurred at interfaces of sieve-tube elements and longitudinal parenchyma. Some of the latter cells were dilated, and many sieve tubes were collapsed. There were few or no sclerenchyma observed in the phloem tissue isolated to the xylem side of the test specimen. Many large, multiseriate rays pulled out of the xylem in a fashion typical of oak species examined earlier in this project. However, similar to phloem failures, no sclerenchyma were seen to be associated with these ray failures.

As a result of measurement data taken on the species included in Appendix Table XXXVII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. In the oaks, sycamore and beech, xylary rays may also contribute to higher adhesion values, especially where sclerenchyma in the rays are lignified into the cambium zone. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark



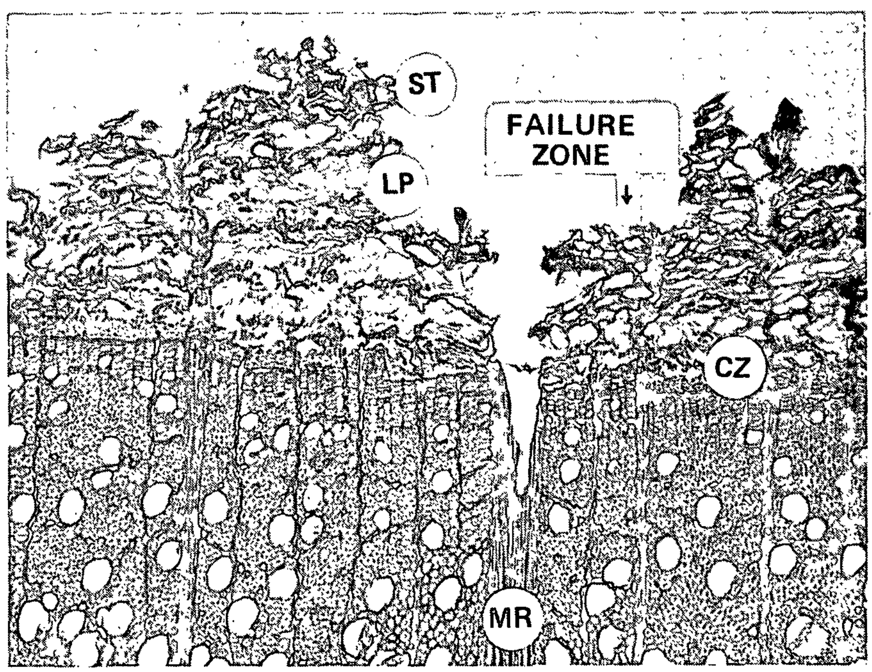


Figure 26. Illustrated Are the Failure Zones for American Beech During the Dormant Season. Failure in the Top Photomicrograph Occurred in the Cambium Zone While the Bottom Photomicrograph Shows the Failure Occurring in the Phloem, Which Is More Typical of Dormant Season Failure. Illustrated also Is the Ray Pull-out Which is Characteristic of the Oaks as well as Beech. Magnification — 38X Top, 75X Bottom. Symbols Illustrate Cambium Zone (CZ), Multiseriate Ray (MR), Sieve Tubes (ST), and Longitudinal Parenchyma (LP)

strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Wilcox, et al. (33), in a study on seasonal variation in bark peeling characteristics of eight species, found the peeling season for American beech to be 46 days, from May 30 to July 16.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the differences encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXVIII summarizes the bark strength and toughness tests made on the wood and bark of American beech. (Appendix Tables XXXIX and XL compare the modulus of elasticity of American beech bark with other species examined in this project.)

TABLE XXVIII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF AMERICAN BEECH[a]

Material	Strength	Toughness
Wood	--	1.02
Inner bark	7.4	0.12[c]
Outer bark	--[b]	

[a]Determinations average of two trees, except inner bark strength which is based on one tree.
[b]Too thin to test.
[c]Measurements based on total bark rather than inner and outer bark.

Bark strength values for American beech inner bark were intermediate compared to other species tested thus far. The outer bark was too thin to test. Toughness values for the sapwood were very high, while toughness values for the whole bark were intermediate. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the high specific gravity of the bark and the intermediate strength and toughness measurements, it appears hammermilling might work fairly well on this species.

Summarized in Table XXIX are the results of the hammermilling tests run on American beech wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling followed by screening, can be expected to result in a fairly good reduction in levels of bark. When the half-sized chips for the two trees (3212-129 and

TABLE XXIX

SUMMARY OF HAMMERMILLING TEST ON AMERICAN BEECH

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-129	Bark	10.2	33.6	15.4	7.6	8.3	24.8	Outer bark stayed attached to inner bark during hammer-milling and screening
	Sapwood	84.5	6.9	2.7	1.2	1.7	3.0	
	Heartwood	85.6	6.2	2.1	1.6	1.6	2.9	
3212-134	Bark	11.8	27.8	14.1	8.2	10.1	27.7	Same as above
	Sapwood	79.6	11.0	3.6	1.3	1.5	3.1	
	Heartwood	82.7	10.7	2.2	0.8	1.3	2.3	

[a] Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28-mesh screen has 28 wires per inch and an opening of 0.589 mm.

3212-134) were hammermilled and the material on the 14-mesh screen retained, the result was 6% wood loss and a 43% reduction in levels of bark. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (58% bark removal and 8% wood loss). Since American beech bark contains a relatively small amount of fiber, the increased bark removal may justify the accompanying increased wood loss. Figure 27 illustrates the effect of hammermilling on wood and bark of red alder. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 27 (25-27). This would require changes in screen design. Summary Table XXXIV compares bark strength, toughness and reaction to hammermilling of American beech with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

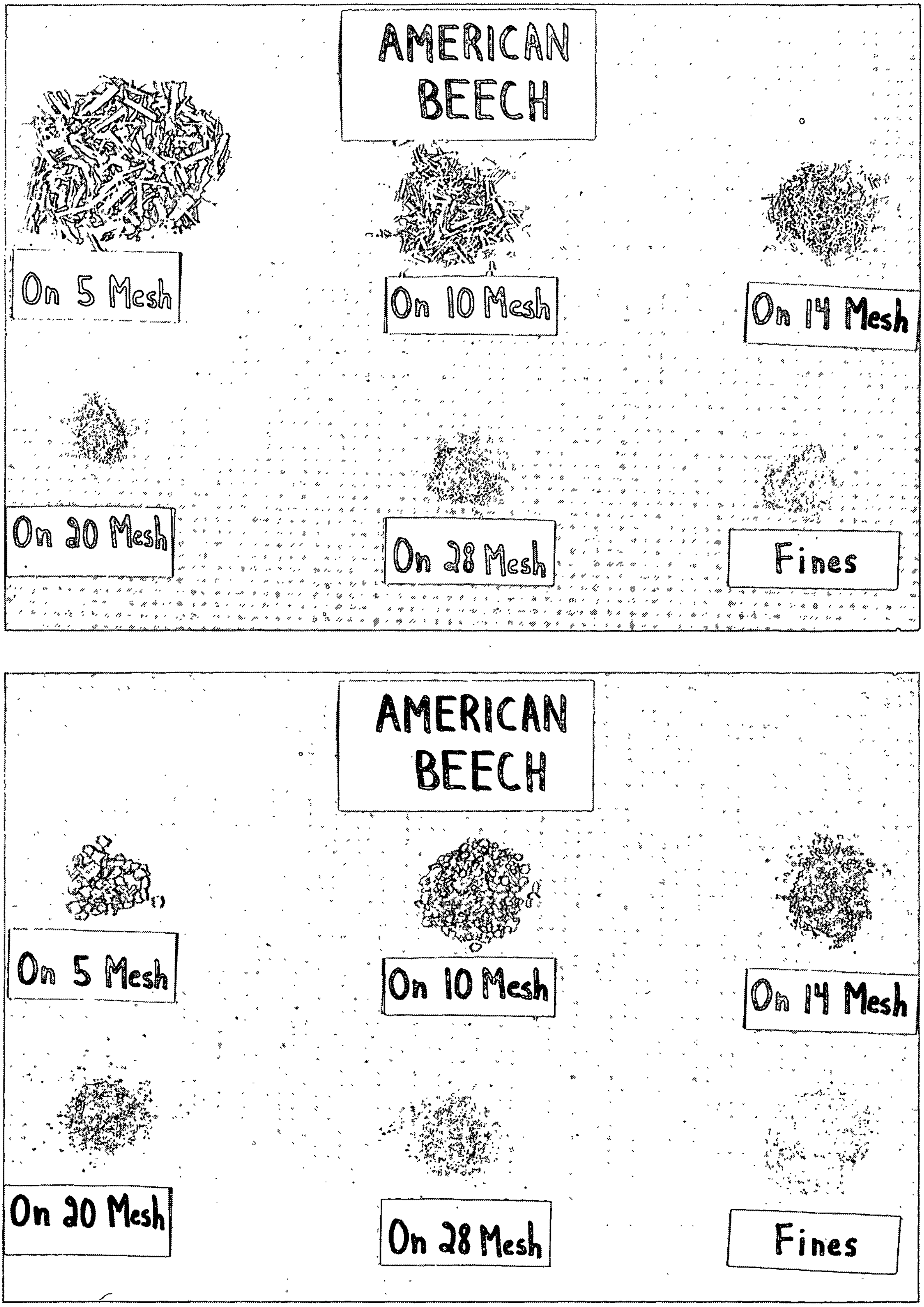


Figure 27. Illustrated Is the Effect of Hammermilling on American Beech Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two American beech trees (IPC 3212-129 and IPC 3212-134) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner and total bark were close in density at various moisture contents. Density determinations were not made on the outer bark because of its thinness.

Figure 28 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which is also an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

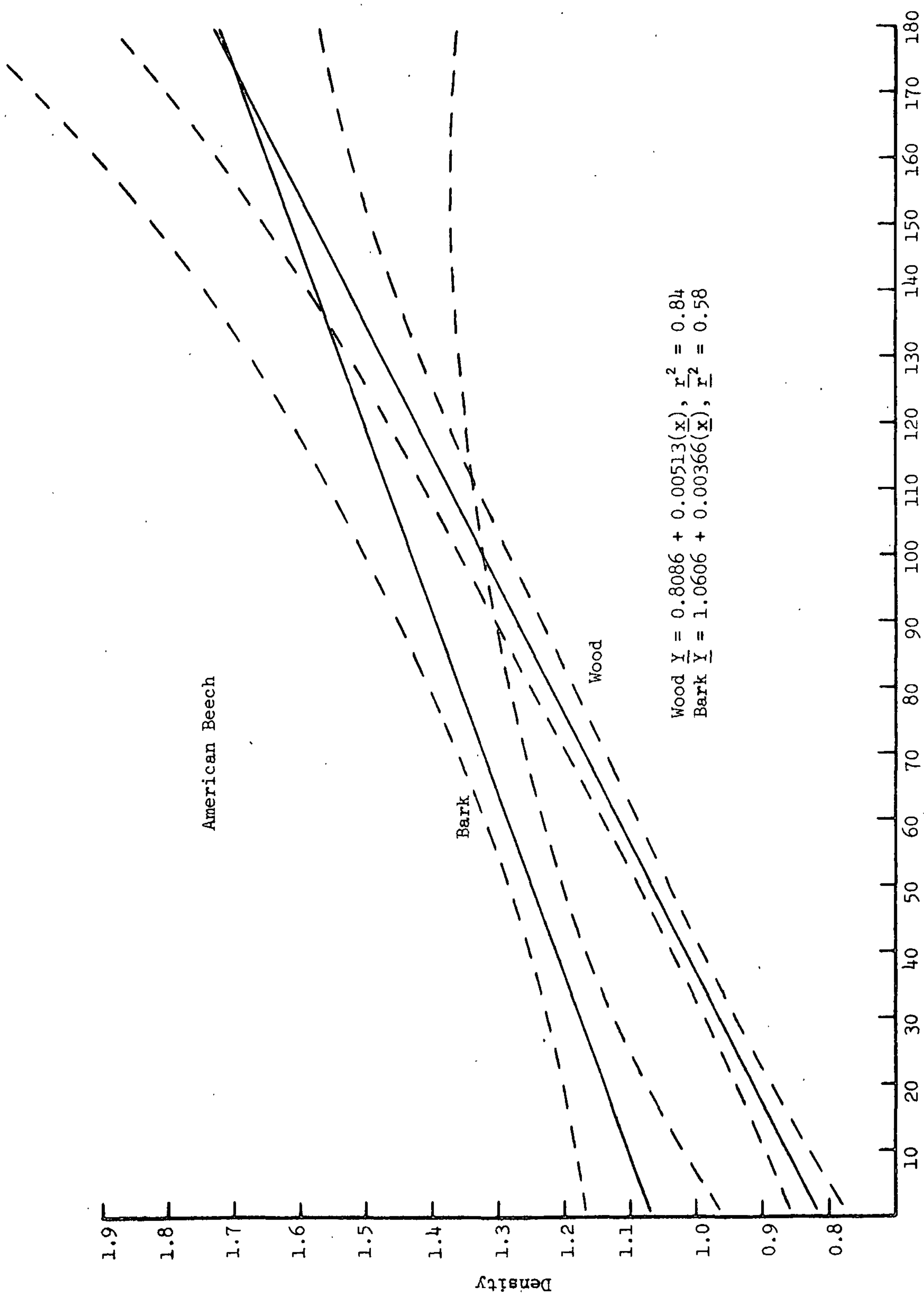


Figure 28. Illustrated Is the Relationship Between Basic Density and Moisture Content for American Beech. The Dashed Lines Are Two Standard Deviations Above and Below the Mean

chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data show that segregation would be possible only when the wood and bark are in a dry condition (30% moisture content or less). At higher moisture contents, both fractions would sink.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated to various moisture contents in polyethylene bags in the refrigerator. Table XXX summarizes the results for American beech. The results were not as expected for this species. The bark sank but more of the wood floated than anticipated, particularly the heartwood of 3212-134. However, Womeldorff (34) found that sapwood of American beech sank much more rapidly than heartwood when placed on a water surface (785 minutes vs. 2718 minutes when both were in a fresh state). After being air-dried for a week, sapwood still sank in a shorter period of time than heartwood (1375 minutes vs. 1806 minutes). It is possible the chips needed a longer length of time, even at that moisture content, to sink.

TABLE XXX

SUMMARY OF DWELL TIME RESULTS FOR AMERICAN BEECH

Sample No.	Moisture Content, %	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-129 Bark	76.6	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-129 Sapwood	63.5	after 5	96.1	3.9
		15	96.1	3.9
		60	97.4	2.6
		240	98.1	1.9
IPC 3212-129 Heartwood	67.0	after 5	88.2	11.8
		15	88.2	11.8
		60	88.2	11.8
		240	94.7	5.3
IPC 3212-134 Bark	69.7	after 5	100	0
		15	100	0
		60	100	0
		240	100	0
IPC 3212-134 Sapwood	65.7	after 5	89.6	10.4
		15	89.6	10.4
		60	89.6	10.4
		240	90.8	9.2
IPC 3212-134 Heartwood	63.8	after 5	51.2	48.8
		15	51.2	48.8
		60	51.2	48.8
		240	51.2	48.8

DATA INTERPRETATION

It appears that it would be possible to use whole-tree chips of American beech without it having much effect on the pulp. When the bark of the trees examined in this project was pulped and screened, 93% of the material passed through the 200-mesh screen. Usable fiber left amounted to 0.25% along with 0.35% sieve tubes. Extractives content of the bark was intermediate (10.6%) and shouldn't cause much of a problem unless large amounts of bark became concentrated in a chip fraction.

There also appear to be several possibilities for upgrading the quality of American beech chip mixtures. Separation and segregation of wood/bark chip mixtures through screening, hammermilling the fractions high in bark and rescreening appear to have some merit. Hammermilling American beech wood and bark chips resulted in a 6% wood loss and a 43% reduction in bark levels based upon material retained on a 14-mesh screen. If material on only the 10-mesh and larger screens is retained, the result is a 58% bark removal and 8% wood loss. Since the bark is in round pieces, rather than stringy, improvements in screening might increase the bark removal without also increasing wood loss.

Segregation through water flotation has some possibility but only when the wood/bark chip mixture is drier than normal (30% or less moisture content). Otherwise, both fractions would sink, with the possible exception of part of the heartwood.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (13), Hooper (14), Biltonen, *et al.* (15), Short, *et al.* (16), Miller (17) and Vais and Vostrov (18). A paper by Taylor (20) contains information on the effect of extraction on volume dimensions and specific gravity.

BARK FUEL VALUE, ASH, CALCIUM, AND SILICA LEVELS

FUEL VALUE

Rising fuel prices have prompted a closer look at the use of bark as fuel. For many end products, removal of the bark is necessary and utilization of bark as fuel is a partial solution to disposal of bark waste. Arola (35) estimates that, if about 60% of the forest residues being generated were recoverable, it would amount to about 6 billion cu. ft. of solid wood annually. If the entire 6 billion cu. ft. were used as fuel to generate steam, the gross potential heat content would be about 1,700 trillion Btu.

Listed in Table XXXI are the Btu values of the species investigated thus far, both in terms of Btu's per ovendry pound and Btu's per cubic foot. Although values are quite similar when figured on the basis of Btu's per ovendry pound, the relative fuel value of the various species becomes more apparent when the specific gravity of the bark is taken into account and heating value is figured in terms of pounds per cubic foot. Also given in Table XXXI are values found in the literature. In most cases, the values found in the literature have been converted to pounds per cubic foot for comparison with IPC values.

Chang and Mitchell (36) reported that the heating value of hardwood barks was lower than that of softwood barks. They found that the barks of all eight softwood species investigated had values greater than 8500 Btu's per dry pound and nine of twelve hardwoods had lower values. However, hardwood barks, on the whole, are higher in specific gravity than softwoods and, when this is taken into account by calculating the values on a cubic foot basis, the fuel value of hardwood barks is generally greater than that of softwood barks.

TABLE XXXI

BARK FUEL VALUES

Species	Total Sp.Gr.	Weight, lb/ft.^{3}	Btu/lb o.d. wt.	Btu/ft.^{3}	Literature Values, Btu, lb/ft.^{3a}
Quaking aspen	0.50	31.2	8,712	271,814	318,041 (37), 263,110 (36)
Sugar maple	0.54	33.7	8,426	283,956	299,572 (37), 246,044 (36)
White birch	0.56	34.9	10,332	360,587	371,160 (37), 329,247 (36)
Northern red oak	0.65	40.6	8,896	361,178	320,090 (4)
Southern red oak	0.70	43.7	8,371	365,813	349,250 (4)
Pin oak	0.71	44.3	8,883	393,517	
Black oak	0.68	42.4	8,340	353,616	
Northern white oak	0.58	36.2	7,536	272,803	
Southern white oak	0.56	34.9	8,046	280,805	256,271 (4)
Post oak	0.56	34.9	6,773	236,378	
Eastern cottonwood	0.31	19.3	8,422	162,545	
Sweetgum	0.42	26.2	7,650	200,430	188,640 (4), 195,190 (36)
Yellow poplar	0.38	23.7	8,956	212,257	
Black tupelo	0.44	27.5	8,102	222,805	
Sycamore	0.60	37.4	7,978	298,377	
White ash	0.50	31.2	8,453	263,734	
Red alder	0.58	36.2	8,760	317,112	305,383 (38), 287,681 (36)
N. black cottonwood	0.40	25.0	8,765	219,125	225,000 (38)
Silver maple	0.57	35.6	8,360	297,616	
American beech	0.67	41.9	7,993	334,906	320,116 (37)
Shagbark hickory	0.72	44.9	8,423	378,193	
Loblolly pine	0.33	20.6	9,320	191,992	193,640 (39)
Slash pine	0.35	21.8	9,327	203,329	196,244 (36), 204,484 (39)
Douglas-fir	0.41	25.6	9,962	255,027	252,595 (40), 258,560 (38)
Western hemlock	0.45	28.1	9,297	261,246	262,735 (40)
Engelmann spruce	0.51	31.8	8,830	280,794	265,816 (36)
Lodgepole pine	0.38	23.7	9,382	222,353	241,503 (36)
Ponderosa pine	0.35	21.8	9,616	209,629	
Western larch	0.32	20.0	8,825	176,500	164,080 (36)
White spruce	0.39	24.3	8,913	216,586	241,399 (37)
Balsam fir	0.40	25.0	9,339	233,475	281,190 (37), 221,525 (36)
Jack pine	0.41	25.6	9,393	240,461	299,155 (37), 224,282 (36)
Red pine.	0.27	16.8	9,070	152,376	
Shortleaf pine	0.35	21.8	9,310	202,958	208,190 (39)
Longleaf pine	0.45	28.1	9,290	261,049	256,553 (39)
Virginia pine	0.54	33.7	9,170	309,029	283,889 (38)
Black spruce	0.42	26.2	9,143	239,547	216,045 (36), 225,582 (37)

[a]Literature cited [Chang and Mitchell (36)] values based on airdry samples with an average moisture content of 6% (range 4.8 to 6.7%).

Fuel value is extremely sensitive to moisture content. Green wood of most species has about 60% of the heat value of well air-dried wood. For instance, a pound of oven-dried red oak wood with a calorific value of 8600 Btu's yields about 5700 Btu's when air dried and about 3400 Btu's when green (41). Figure 29, taken from data supplied by Cunningham and De Vriend (42) shows the drop in usable Btu's at increasing moisture contents.

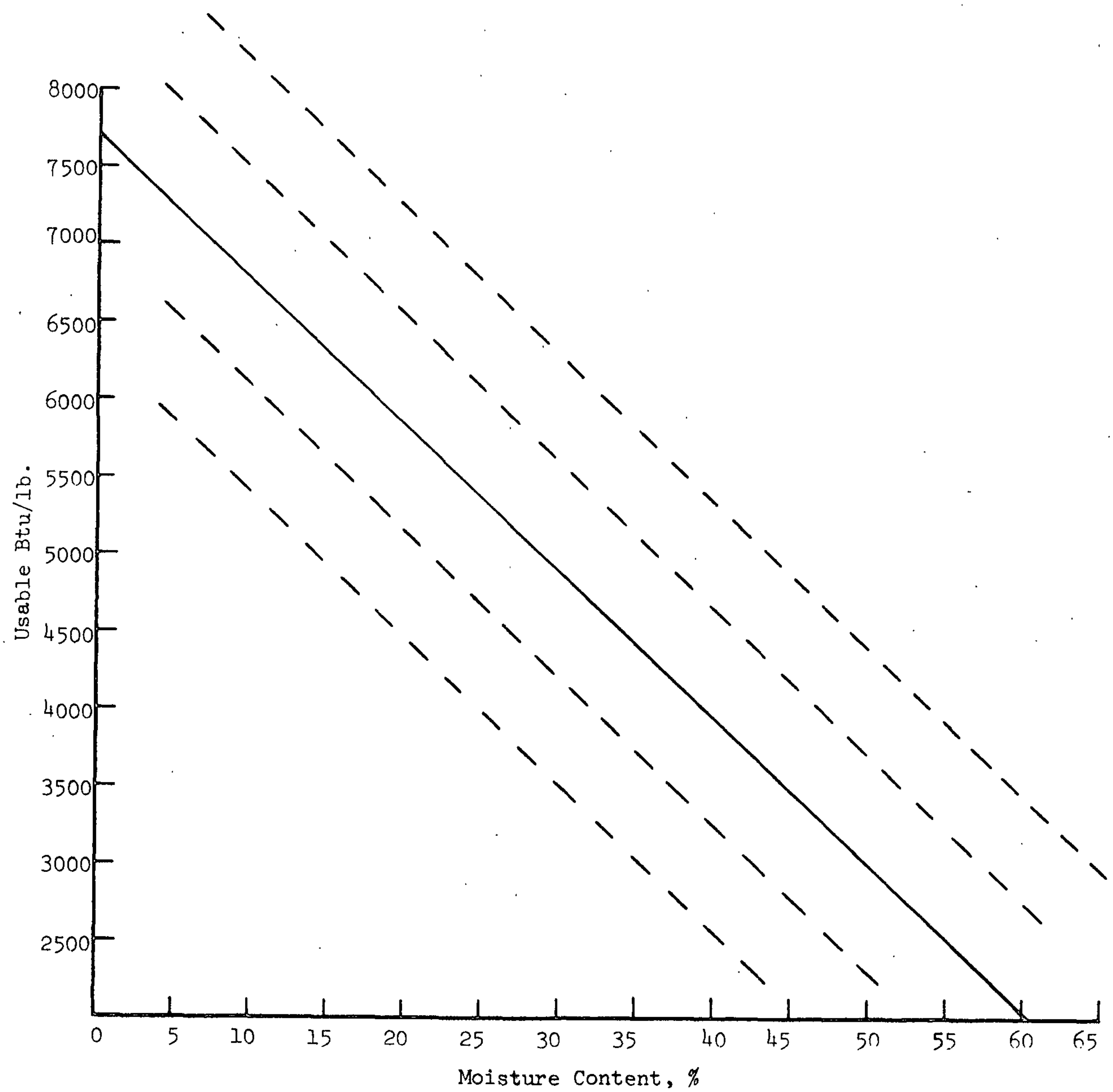


Figure 29. Illustrated Is the Effect of Moisture Content on Usable Btu's per Pound

ASH, CALCIUM, AND SILICA LEVELS

Listed in Table XXXII are percent ash, calcium and silica on an oven-dry basis. Ash is the noncombustible part of the bark and needs to be removed, at least in part, after burning. According to Chang and Mitchell (36), a high percentage of ash tends to give lower heat of combustion values. Wood has a low ash content, generally less than 1% of dry weight (40). IPC ash values for bark ranged from 0.8% for loblolly and slash pine to 12.6% for northern white oak. Softwoods generally had lower ash values than did hardwoods. Also listed in Table XXXII are values obtained from the literature.

Calcium is one of the principal inorganic elements in bark. When bark is pulped, high levels of calcium can be expected to increase recovery system scaling problems. More rapid scaling increases evaporator down time and reduces heat transfer. Low percentages of calcium in bark are therefore desirable. Trends were the same for percent calcium with loblolly and slash pine, again the lowest of the species investigated (0.2%), and northern white oak, the highest (5.2%). Also, as with percent ash, softwoods generally had lower values than did hardwoods.

Insoluble silicates are naturally occurring minerals that are commonly found in soils. They include not only extremely hard and abrasive types of minerals but silicon as an element in clay minerals of soils. Silica (SiO_2) levels are of interest because, in the form of minerals, they represent the principal acid insoluble fraction in bark and, as such, are expected to remain as one possible abrasive contaminant in pulps.

TABLE XXXII

PERCENT ASH, CALCIUM AND SILICA IN BARK

Ovendry Basis

Species	Ash, %[a]	Literature Values, ash, %	Calcium, %	Silica, %
Quaking aspen	5.2	2.8 (36), 3.9 (37)	1.9	0.03
Sugar maple	8.3	6.3 (36), 5.0 (37)	3.0	0.19
White birch	2.4	1.5 (36), 1.7 (37)	0.7	0.06
Northern red oak	5.4	5.4 (36)	2.2	0.12
Southern red oak	6.5		2.6	0.14
Northern white oak	12.6	10.7 (36)	5.2	0.29
Southern white oak	8.2	10.7 (36)	3.4	0.42
Eastern cottonwood	6.2		2.5	0.18
Sweetgum	10.5	5.7 (36)	3.8	1.41
Yellow poplar	2.8		1.0	0.05
Black tupelo	7.3		2.9	0.11
Sycamore	7.1		3.0	0.06
White ash	4.4		1.6	0.13
Red alder	5.9	3.1 (36), 3.1 (38)	1.4	0.05
N. black cottonwood	5.0		1.1	0.08
Silver maple	3.6		0.6	0.18
Shagbark hickory	7.3		2.5	0.08
Post oak	17.8		5.1	0.02
Pin oak	6.3		2.1	0.1
Black oak	7.5		2.8	0.06
American beech	10.5	9.4 (43)	3.4	1.1
Loblolly pine	0.8	0.4 (39)	0.2	0.09
Slash pine	0.8	0.6 (36), 0.7 (39)	0.2	0.04
Douglas-fir	1.2		0.3	0.06
Western hemlock	1.7		0.3	0.04
Engelmann spruce	2.6	2.5 (36)	0.8	0.08
Lodgepole pine	2.2	2.0 (36)	0.6	0.16
Ponderosa pine	0.7		0.2	0.16
Western larch	2.4	1.6 (31)	0.6	0.26
White spruce	4.2	3.5 (38)	1.2	0.14
Balsam fir	3.4	2.3 (36), 2.6 (37)	1.0	0.10
Jack pine	1.3	1.7 (36), 2.1 (37)	0.3	0.14
Red pine	1.3		0.3	0.03
Shortleaf pine	1.6	0.7 (39)	0.4	0.10
Longleaf pine	0.6	0.7 (39)	0.2	0.004
Virginia pine	2.2		0.7	0.01
Black spruce	3.1	1.8 (37)	0.8	0.10

[a]Ashed at 600°C.

The SiO_2 levels reported in Table XXVI are levels from bark samples which have been carefully harvested and transported and represent SiO_2 levels in bark relatively free from contaminating soil minerals. Some measure of silica levels (principally sand) that are added by harvesting and transporting could be obtained by comparing appropriately sampled and analyzed wood and bark samples from company operations with the relatively soil-free silica (SiO_2) levels reported in Table XXXII.

There has been greatly increased interest in bark Btu's, calcium, ash and silica content, resulting in a number of publications in this area. Additional publications of interest include those by Corder (38,44), Junge (45-46), Howard (47), Johnson (48), Smith (49), Burnett (50) and Kowalczyk (51).

DWELL TIME STUDY

This small study was run to determine whether the density-moisture content curves could be used to accurately predict the sinking or floating of bark and wood chips at specified moisture contents. Simulated bark and wood chips were prepared, following the technique developed in Project 3212, from northern black cottonwood, white ash and longleaf pine. The moisture content of the chips was determined on an ovendry basis. The simulated bark and wood chips for each species were placed separately in polyethylene bags and appropriate amounts of water added to cause one fraction to float and the other fraction to sink. Moisture contents to be used were picked off the density-moisture content curves. The samples were equilibrated for ten days in the refrigerator. After equilibration, a small sample was removed from each bag for percent moisture determinations and the rest of the sample was placed on a water surface. The chips that did not sink immediately were briefly pushed under the water to wet all sides. Observations were then made on the length of time it took the chips to pick up enough water to sink (or not sink). Time periods checked were 5 minutes, 15 minutes, 30 minutes, 60 minutes, and 4 hours. Material sinking at each of these times was picked off, oven-dried and the relative percentage determined. Table XXXIII gives the results of this study. Although the samples were checked at the several time periods, the only results given in the table are after four hours.

It does appear that the density-moisture content curves can be used to predict the sinking and floating of wood and bark chips. However, as can be seen from the table, these curves are rough estimates because of the variation in density between trees of the same species. Also, mill chips would be smaller and less uniform and would probably behave somewhat differently for that reason.

TABLE XXXIII

TEST OF ACCURACY OF DENSITY-MOISTURE CONTENT CURVES

Species	Fraction	Moisture Content at Which Sinking Should Occur, %	Moisture Content Used, %	Percent Sinking After 4 Hr
Longleaf pine	Wood	50	58	39
			64	52
	Bark	145	69	0
			67	1
N. black cottonwood	Wood	180	95	0
			165	22
	Bark	80	98	42
			126	79
White ash	Wood	55	72	16
			75	30
	Bark	130	85	1
			101	2

It also appears from this study that neither wood nor bark take up water very quickly when floating on a water surface. Therefore, if segregation is attempted with material in a fresh state (100% moisture content, ovendry basis), density differences must be present when fresh that will make segregation possible. It is not feasible in most cases to expect one fraction to take up water faster than the other to the point that adequate segregation would occur. The time period involved would be too long.

BETWEEN-SPECIES COMPARISONS

An important aspect of the characterization of the species covered in these reports is the way they relate to each other, both in terms of improving our overall understanding of bark and judging which species can be handled in a similar manner, perhaps in a chip mixture. Tables XXXIV and XXXV provide a quick method of comparing the basic information available for the 37 species investigated.

Considered in this report were three oaks, post, pin and black oak, shagbark hickory and American beech. The addition of these three oaks to the four oaks already investigated should greatly improve our understanding of this important pulpwood species. Shagbark hickory, although not as commercially important, is a species with a large amount of bark fiber and one in which the bark is very strong. It represents an extreme and the information gained from it is valuable for that reason. American beech is the fifth species considered. Since no conifers were covered in this report, the detailed discussion regarding between species comparisons for conifers that was presented in Progress Report Six (p. 116-122) remains valid and has not been repeated in this report.

For most species investigated, the hardwood barks were similar or higher in specific gravity than the conifer barks (Engelmann spruce, Virginia pine, eastern cottonwood and yellow-poplar are exceptions). The specific gravity of the hardwood barks investigated show no consistent relationship to the specific gravity of the wood. For some species, the wood has a higher specific gravity, for others the bark has the higher specific gravity and there are several species, like gum and yellow-poplar, where the specific gravity of the wood and bark is very similar. A relationship between wood and bark specific gravity has been established for the oaks, however. For trees in the white oak group, which includes northern and

TABLE XXXIV

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULP SPECIES

Characteristic	Quaking Aspen	Eastern Cottonwood	Sweetgum	Sugar Maple	White Birch	Northern Red Oak	Southern Red Oak	Northern White Oak	Southern White Oak	Sycamore	Yellow Poplar
Specific gravity (o.d. wt./green vol.)											
Wood	0.38	0.38	0.44	0.59	0.49	0.56	0.60	0.64	0.67	0.45	0.39
Total bark	0.50	0.31	0.42	0.54	0.56	0.65	0.70	0.58	0.56	0.60	0.38
Inner bark	0.40	0.29	0.51	0.69	0.57	0.53	0.68	0.65	0.70	0.60	0.38
Outer bark	0.55	0.32	0.36	0.49	0.54	0.71	0.70	0.52	0.44	--	0.42
Extractives, % (airdry)											
Wood	3.0	1.4	2.6	1.0	4.0	4.5	4.8	2.4	4.6	2.2	3.9
Bark	15	7.9	10.2	6	17	11	11.6	7.2	8.6	8.1	13.8
Density at 100% moisture (green wt./green vol.)											
Wood	0.79	0.84	0.84	1.24	1.01	1.06	1.25	1.30	1.38	0.98	0.79
Bark	1.15	0.81	0.87	1.08	1.16	1.18	1.39	1.05	1.13	1.21	0.82
Pulp yield, % (bark)	33.8	35.4	34.9	33.9	36.3	28.4	30.7	35.4	36.6	31.4	32.3
Usable bark fiber, %[a]	10	9	5	3	0	5	4	3	3	0	13
Sclereids remaining, %[a]	1	<0.1	--	0.2	0.7	0.2	--	--	--	--	0
Fiber location[b]	IB	IB	IB	IB	--	IB	IB	IB	IB	--	IB
Sclereid location[b]	IB	--	IB	IB	IB	IB	IB-OB	IB-OB	IB-OB	IB	--
Wood/bark adhesion, kg/cm^2											
Growing season	6.4	4.4	10.2	5.8	5.1	2.5	5.4	4.8	--	--	--
Dormant season	11.4	13.5	15.3	10.1	12.0	8.4	8.2	7.8	7.2	14.8[e]	16.6
Bark strength, kg/cm^2											
Inner bark	9.0	17.7	8.1	1.4	1.6	2.1	3.6	4.6	4.7[d]	6.1	13.4
Outer bark	4.9	4.2	5.2	4.7	9.8	4.6	3.4	3.2	--	--	10.4
Toughness											
Inner bark	0.22	0.14	0.20	0.25	0.10	0.13	0.11	0.16	0.12	0.15	0.20
Outer bark	0.10	0.11	0.11	0.10	0.10	0.18	0.14	0.10	0.09	--	0.18
Sapwood	0.45	0.38	0.28	1.20	0.68	0.93	0.55	0.62	0.98	0.50	0.23
Hammermilling[c]											
Bark removed, %	34	18	32	29	38	34	46	37	38	45	23
Wood loss, %	5	5	7	5	6	10	6	5	3	7	7

Characteristic	Black Tupelo	White Ash	Red Alder	Northern Black Cottonwood	Silver Maple	Post Oak	Pin Oak	Black Oak	Shagbark Hickory	American Beech
Specific gravity (o.d. wt./green vol.)										
Wood	0.52	0.57	0.37	0.31	0.42	0.64	0.61	0.57	0.65	0.60
Total bark	0.40	0.48	0.58	0.40	0.57	0.56	0.71	0.68	0.72	0.67
Inner bark	0.37	0.51	0.55	0.38	0.51	0.65	0.57	0.69	0.69	0.67
Outer bark	0.37	0.43	0.62	0.42	0.61	0.53	0.74	0.68	0.81	--
Extractives, % (airdry)										
Wood	3.0	4.0	2.1	2.3	3.5	4.3	4.4	5.0	3.2	1.5
Bark	10.6	12.6	6.0	20.0	6.6	8.2	14.9	15.4	14.6	10.6
Density at 100% moisture (green wt./green vol.)										
Wood	0.88	1.20	0.77	0.63	0.91	1.27	1.30	1.29	1.41	1.32
Bark	0.85	0.95	1.15	1.04	1.11	1.14	1.31	1.69	1.23	1.43
Pulp yield, % (bark)	31.4	35.7	27.0	26.0	32.0	46.2	26.5	31.4	28.3	37.0
Usable bark fiber, %[a]	1-10	16	0	12	6	4	2	5	15	0.25
Sclereids remaining, %[a]	0	0	0	0	2.5	--	--	--	0	--
Fiber location[b]	IB	IB	--	IB	IB	IB	IB	IB	IB	IB
Sclereid location[b]	IB-OB	--	IB	IB-OB	IB	IB-OB	IB-OB	IB-OB	--	IB-OB
Wood/bark adhesion, kg/cm^2										
Growing season	--	--	--	--	6.1	--	--	--	3.8	--
Dormant season	13.5	23.8	13.0	18.7	14.1	12.2	12.9	21.5	30.6	14.0
Bark strength, kg/cm^2										
Inner bark	9.6	20.0	8.2	13.9	3.4	6.8	10.5	11.7	25.0	7.4
Outer bark	10.5	4.2	5.9	7.3	--	3.4	9.9	9.7	72.7	--
Toughness										
Inner bark	0.20	0.45	0.10	0.10	0.17	0.20	0.24	0.29	0.90	0.12[d]
Outer bark	--	0.20	0.02	0.07	0.12	0.18	0.14	0.10	0.71	--
Sapwood	0.56	0.68	0.50	0.30	0.50	0.66	0.64	0.86	1.48	1.02
Hammermilling[c]										
Bark removed, %	39	24	48	26	14	47	33	37	11	43
Wood loss, %	5	6	8	5	4	6	6	7	4	6

[a] Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b] Major proportion located in either the inner bark (IB) or outer bark (OB).
[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d] Test performed on total bark.
[e] Sample failed in tensile.

TABLE XXXV

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock	Lodgepole Pine	Ponderosa Pine	Engelmann Spruce	Western Larch	Red Pine	Shortleaf Pine	Longleaf Pine	Virginia Pine	Black Spruce
Specific gravity (o.d. wt./green vol.)																
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40	0.39	0.39	0.34	0.50	0.39	0.47	0.55	0.50	0.40
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45	0.38	0.35	0.51	0.33	0.27	0.35	0.45	0.54	0.42
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46	0.32	0.34	0.41	0.37	0.20	0.26	0.25	0.27	0.33
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45	0.45	0.35	0.52	0.33	0.29	0.35	0.48	0.56	0.46
Extractives, % (airdry)																
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6	3.5	5.3	2.8	1.4	3.5	4.1	4.3	4.1	1.5
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7	15.7	15.7	24.4	14.4	5.8	7.7	8.8	8.2	14.7
Density at 100% moisture (green wt./green vol.)																
Wood	0.70	0.75	0.79	0.88	1.10	0.815	0.80	0.89-0.92	0.96	0.80	1.43	0.74	1.10	1.20	1.08	0.84
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85	0.74-0.95	0.62	1.14	0.61	0.62	0.72	0.90	1.03	0.97
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8	27.4	29.1	24.4	27.8	33.0	20.1	26.4	23.2	26.0
Usable bark fiber, %[a]	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0
Sclereids or phellem cells remaining, %[a]	1.5	12.0	<1	1	2	2	11	<1	1	3	0	<1	<1	<1	<1	3
Fiber location[b]	--	--	--	--	--	IB-OB	--	--	--	--	IB	--	--	--	--	--
Sclereid or phellem cell location[b]	IB-OB	IB	OB	OB	OB	IB-OB	IB-OB	OB	OB	OB	--	OB	OB	OB	OB	IB-OB
Wood/bark adhesion, kg/cm^2																
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6	2.2	5.0	3.4	1.2	--	--	--	--	--
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2	5.6	9.6	12.5	4.4	9.6	8.6	5.2	7.2	18.1
Bark strength, kg/cm^2																
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0	--	4.6	--	4.5	--	7.4	--	4.6	10.6
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--	2.4	4.9	4.2	4.4	5.6	2.7	5.8	4.0	7.6
Toughness																
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12	0.10	0.10	0.24	0.12	0.16	0.16	0.21	0.30	0.22
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10	0.08	0.08	0.16	0.10	0.12	0.10	0.10	0.16	0.10
Sapwood	0.34	0.42	0.34	0.54	0.54	0.58	0.28	0.28	0.26	0.26	0.28	0.60	0.94	0.89	0.61	0.45
Hammermilling[c]																
Bark removed, %	23	44	26	34	36	28	24	31	26	25	26	26	29	35	31	26
Wood loss, %	4	6	5	6	5	4	3	4	4	4	6	5	4	6	4	6

[a] Usable bark fiber and sclereids or phellem cells remaining are the fibers and sclereids retained on the 60- and 100-mesh screens.
[b] The percentage given is the yield based on whole bark samples.
Major proportion located in either the inner bark (IB) or outer bark (OB).
[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

southern white oak and post oak, the specific gravity of the wood is higher than that of the bark while for the red oak group (northern and southern red oak, pin oak and black oak) the wood is lower in specific gravity than the bark. Conifer barks are generally similar or lower in specific gravity than the associated sapwood (Engelmann spruce was an exception). The lack of a consistent specific gravity relationship in hardwoods makes the use of a water flotation procedure for mixed hardwood chips virtually impossible except for a few associated species like red alder and northern black cottonwood which have similar densities at the same moisture content. Water quality considerations have also decreased the usefulness of this approach.

Hardwood barks, with the exception of sycamore, white birch and red alder, have varying levels of fiberlike structures in the bark. Conifers, in contrast, with the exception of Douglas-fir and to a lesser extent western larch, contain no fiberlike elements in the bark*. These results suggest that most conifer barks, when pulped, should <u>not</u> be expected to produce fiber that will contribute to the strength of the paper and board being produced. There is also considerable evidence that the high amounts of thin-walled cells (sieve cells and parenchyma cells) produced when high levels of bark are pulped could result in paper machine drainage problems. Also to be considered when bark levels of 10-15% are being pulped are the economics of such factors as lower pulp yields, brightness, higher permanganate number and higher chemical consumption. Major monetary losses have been described when daily production is reduced by 10% because the mill is "digester-limited" and pulp production is decreased as a result of pulping wood/bark mixtures [Keays and Hatton (<u>54</u>)]. However, the presence of some bark in the pulp furnish will be

*There is evidence from the literature (<u>52</u>,<u>53</u>) that western red cedar, along with several other species of the Cupressaceae family, also have fiberlike elements in the bark.

stimulated by the trend to greater utilization of the entire tree. The amount of bark tolerated in the pulp furnish and the efforts expended to separate and segregate bark will be determined in part by its value for fuel and its use for chemicals and board (55).

The fiber content of hardwood bark offers an interesting situation when some type of mechanical procedure is used to break up and remove the bark. The part of the bark that does not respond to this type of treatment is usually the stringy, fiber-rich bark. As a result, a procedure that removes much of the non-fibrous bark (usually outer bark) and retains for pulping the stringy bark that behaves like wood during mechanical treatment, could result in a fairly favorable fiber yield situation. White ash, black tupelo, yellow poplar, quaking aspen, eastern cottonwood, northern black cottonwood and shagbark hickory are examples of species that have been examined that could be a source of modest amounts of bark fiber. Of the species examined in this project, shagbark hickory had the second greatest amount of usable fiber in the bark (15%), followed by northern black cottonwood with 12%. White ash had the largest amount of usable fiber (16%). The oaks ranged from 2-5% usable fiber in the bark.

There has been no consistent pattern with regard to levels of bark extractives with the exception that the levels in the bark are from about three to eight times as high as in the wood. Browning (56) reported that mineral substances in the bark can be more than ten times higher than in the corresponding wood. Most conifer barks have higher levels of extractives than do hardwood barks. Red pine and the southern pines (slash, loblolly, shortleaf, longleaf, and Virginia) are the exception with extractives levels from only 5.8 to 8.8%. Aspen, northern black cottonwood, white birch, shagbark hickory, pin and black oak are hardwood species with high levels of extractives and Engelmann spruce and balsam fir are the two conifers with the highest levels of extractives. Even with these latter species, because of the relatively thin bark involved on pulpwood-sized trees, pitch problems are not expected to be serious unless, as the result of concentrating large amounts of bark from screening procedures, high levels of bark are pulped. It is also important to remember that seasoning can diminish the content of extractives in bark and our values are based on airdry samples in most cases, rather than fresh samples.

Wood/bark adhesion during the growing season was low and very similar for all species investigated (except sweetgum). Quite consistently, the zone of failure occurred in the cambium zone or the newly-formed nonlignified wood fibers adjacent to the cambium zone. Dormant season adhesion was, as expected, higher than growing season adhesion and the failure zone usually occurred in the partially mature sieve and parenchyma cells of the inner bark, just outside the cambium zone. Dormant season wood/bark adhesion tends to be slightly higher for hardwoods than for conifers and, in certain instances, seems to be associated with the presence of large numbers of phloem fibers in the inner bark. Medium-high dormant season adhesion was associated with intermediate levels of inner bark fibers in aspen, cottonwood, and black tupelo. High wood/bark adhesion was associated with high levels of inner bark fibers in yellow-poplar, northern black cottonwood, white ash and shagbark hickory. Moderate levels of wood/bark adhesion in white birch, red alder and sycamore appear to be exceptions to the rule. Another factor influencing adhesion seems to be the large, multiseriate rays which appear in the oaks, American beech and sycamore. These rays, located in the xylem, have spearheads of sclerotic ray parenchyma extending into the cambium zone. Because of these spearheads, wood/bark adhesion is very likely increased. The appearance of the failure zone cross sections examined for these species tends to confirm this observation.

As discussed in previous reports, breaking the bond between wood and bark (separation) is an important first step in any segregation procedure. A very practical way of separating bark and wood during the growing season, and in some instances during the dormant season, is through the action of the chipper. Arola (57), working with northern hardwoods, found that chipper action during the growing season gave better results than during the dormant season with less than 2% bark remaining on the chips from 4-6 and 8-inch diameter bolts. Erickson (58) obtained similar results for spruce, balsam fir and jack pine. Results during the growing season were good; however, separation during the dormant season was poor (36-72%) for bolewood and even less for the thin-barked branchwood, with the poorest month of separation being November (36-48%). Erickson (58), working with maple, reported 96% separation during the chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts, although more fines resulted.

Despite the fairly consistent location of the wood/bark failure zone, there are, particularly in the dormant season, major differences between species in the ability of the chipper to cause separation. Preliminary Institute of Paper Chemistry investigations suggest inner bark strength and chipper knife impact on the cambium zone are important factors. For hardwoods, and possibly some conifers, the presence of fibers and sclereids in the inner bark influence inner bark strength. Bark thickness and wood density (or frozen wood) influence chipper knife impact at the cambium zone. Chipper separation during the dormant season is expected to be least effective on thin-bark, low-density woods with fiber in the inner bark. White spruce, although it has no fiber in the inner bark, is an example of a thin-barked, low-density wood in which dormant season separation is poor. Shagbark hickory is the extreme example of a high density wood in which the bark is strong and contains a large amount of fiber. It appears a species like this would resist chipper action and this was the case in IPC trials with chipper action only moderately effective in separating wood and bark.

Mechanical treatment of bark continues to look promising as a method of upgrading low-quality chips high in levels of bark. The approach attempts to take advantage of the lower strength and toughness of bark with the result that there will be a reduction in the size of the bark particles sufficient to allow removal by screening. For hardwoods, when a hammermilling type action is employed, good bark removal seems to be best correlated with high specific gravity. For conifers, correlations between bark removal and strength properties are quite low. The most effective reduction in bark levels, particularly with hardwoods, results when specific gravity is high, bark strength and toughness is low and the bark is relatively thick. Northern red oak and red alder are examples where these relationships hold and the reduction in bark levels are higher than normal. When inner bark strength is high because of high levels of bark fibers, the stringy inner bark reacts like wood and is retained with the wood. Although such inner bark is classified as bark contamination, modest levels should have no adverse influence on paper properties.

Chip shredding is a technique that was developed about twenty years ago and has been used mainly with conifers that are cooked by the kraft pulping process. As described in Progress Report Five, (page 119), at least two pieces of commercial equipment have been used in shredding investigations (Jones Vertiflex and Sprout-Waldron milling machines)*. Shredded wood chips have been described as giving

*The Jones Vertiflex is manufactured by the Jones Division of the Beloit Corporation and the Sprout-Waldron milling machine is produced by Sprout Waldron & Co., Inc.

increased yields, lower chemical consumption and either reduced cooking temperature and/or cooking times (59,60). As described in Progress Report Six, chip shredding was tried using a relatively high moisture content red pine sample. Using a procedure that involves retaining the material on two and four-mesh screens and using for fuel the material that was retained on or passed through the ten-mesh screen resulted in a 9% wood loss and a chip sample still containing 8% bark*. Northern red oak, in contrast, has a high wood and bark specific gravity, moderate bark toughness and strength and, when shredded and screened, had just a 5% wood loss and a bark contamination level of just 6%. These results look quite promising in view of the fact that the treatment has the potential for grit removal, much of the retained bark has a reasonable fiber content and the discarded material is a valuable source of energy.

Bark ash content, and calcium in particular, is of importance because of its apparent influence on recovery system scaling problems. Levels of ash (and calcium) in the barks of conifers are quite consistently less than in hardwood bark. White spruce, yellow poplar and white birch are exceptions. Calcium levels range from 0.2% in longleaf, slash, loblolly and Ponderosa pine to 5.2% in northern white oak. Since the levels in the bark are about 10-15 times as high as in the wood of most hardwood pulp species, pulping of whole-tree chips can be expected to increase recovery system scaling problems.

The fuel values of the bark of all pulpwood species investigated are summarized in this report. The ovendry Btu values for hardwoods vary more than for

*This information is slightly different than reported earlier because of a need to recalculate the results because of additional information obtained on the original bark input.

conifers. Our data for hardwood barks confirms Chang and Mitchell's (36) observations and indicate that there is a negative correlation between ash content and ovendry Btu values. This relationship is less evident for the conifers investigated. Both hardwood and conifer barks, when the Btu values are converted to a cubic foot basis, demonstrate fairly major differences. These differences are due to bark specific gravity differences. Values range from 152,780 for red pine and 162,500 for cottonwood to 365,800 Btu/cubic ft for southern red oak. Western larch also had a relatively low value for a conifer (176,500 Btu/cubic ft) while Virginia pine had the highest value (309,000 Btu/cubic ft). The potential of bark and other forest residue as fuel was estimated by Arola (35) and covered in the section on Fuel Value. Briefly, he estimated a gross potential heat content of 1,700 trillion Btu if 60% of the forest residues being generated were recoverable.

PLANS

The barks of 37 pulpwood species have been characterized in this project, including quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); white spruce, balsam fir, jack pine, eastern cottonwood (Report Three); southern white oak, northern white oak, southern red oak, sweetgum (Report Four); lodgepole pine, ponderosa pine, Engelmann spruce, western larch (Report Five); red pine, shortleaf pine, longleaf pine and Virginia pine (Report Six); sycamore, yellow poplar, black tupelo and white ash (Report Seven); black spruce, red alder, northern black cottonwood and silver maple (Report Eight); and shagbark hickory, post oak, pin oak, black oak and American beech (Report Nine). There will be one more bark characterization report issued which will cover red maple, green ash, black willow, eastern hemlock, and eastern white pine. In addition, we plan to summarize, in a special report, the overall findings of the bark characterization research.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

Dbh. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Paratracheal. Said of xylem parenchyma which occurs at the edge of the annual ring, around the vessels, but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Scalariform. Like a ladder.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Sclerotic. Hard, thick-walled, and often lignified.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Suberized. Transformed into cork.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylose. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

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APPENDIX

TABLE XXXVI

SAMPLE TREE INFORMATION

Species	Tree No.	Age, yr	Height, ft.	dbh, inch	Location
Shagbark hickory	3212-121	Unknown			Wisconsin
	3212-122	87+	Unknown		Wisconsin
	3212-124	45	Unknown		Tennessee
Post oak	3212-120	65	65	12.0	Tennessee
	3212-125	58+	38	7.8	Alabama
	3212-126	65+	30	7.6	Alabama
Pin oak	3212-127	48	30-35	7.9	Pennsylvania
	3212-128	55	36	8.2	Pennsylvania
	3212-130	36	33	9.0	New York
Black oak	3212-119	45	75	9.0	Tennessee
	3212-132	53	62	7.6	West Virginia
	3212-133	58	60	9.0	Lower Michigan
American beech	3212-123	90	59	10.6	New York
	3212-129	60	44	8.6	Pennsylvania
	3212-134	61	62	8.2	Lower Michigan

TABLE XXXVII

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2 Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Lodgepole pine	2.2	5.6
Ponderosa pine	5.0	9.6
Engelmann spruce	3.4	12.5
Western larch	1.2	4.4
Red pine	--[a]	9.6
Shortleaf pine	--[a]	8.6
Longleaf pine	--[a]	22.0
Virginia pine	--[a]	7.2
Black spruce	--[a]	18.1
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4
Southern red oak	5.4	8.2
Northern white oak	4.8	7.8
Southern white oak	--[a]	7.2
Sweetgum	10.2	15.3
Sycamore	--[a]	14.8[b]
Yellow-poplar	--[a]	16.6
Black tupelo	--[a]	13.5
White ash	--[a]	23.8
Red alder	--[a]	13.0
Northern black cottonwood	--[a]	18.7
Silver maple	6.1	14.1
Shagbark hickory	3.8	27.0
Post oak	--[a]	12.2
Pin oak	--[a]	12.9
Black oak	--[a]	21.5
American beech	--[a]	9.3

[a]Growing season adhesion not measured.
[b]Samples failed in tensile.

TABLE XXXVIII

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2 Inner Bark	Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	--	7.4
Jack pine	2.3	2.3
Balsam fir	1.7	1.4
Lodgepole pine	--	2.4
Ponderosa pine	4.6	4.9
Engelmann spruce	--	4.2
Western larch	4.5	4.4
Red pine	--	5.6
Shortleaf pine	7.4	2.7
Longleaf pine	--	5.8
Virginia pine	4.6	4.0
Black spruce	10.6	7.6
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6
Southern red oak	3.6	3.4
Northern white oak	4.6	3.2
Southern white oak	4.7[a]	--
Sweetgum	8.1	5.2
Sycamore	6.1	--
Yellow-poplar	13.4	10.4
Black tupelo	9.6	10.5
White ash	20.0	4.2
Red alder	8.2	5.9
Northern black cottonwood	13.9	7.3
Silver maple	3.4	--
Shagbark hickory	25.0	72.7
Post oak	6.8	3.4
Pin oak	9.1	9.9
Black oak	11.7	9.7
American beech	7.4	--

[a]Bark strength measured on total bark rather than inner and outer bark.

TABLE XXXIX

MODULUS OF ELASTICITY VALUES[a]
HARDWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
Northern white oak	1	19100	10400	6700
	2	42800	6700	2700
Sugar maple	1	31600	14000	3500
	2	43600	15900	3300
Quaking aspen	1	17000	14000	6500
	2	24400	8200	--
Northern red oak	1	23700	13500	10900
	2	34100	6800	7800
White birch	1	34200	6900	1900
	2	33400	8400	2200
Eastern cottonwood	1	33900	23200	4300
	2	48700	17900	7200
Silver maple	1	31500	32000	13900
	2	32600	25000	11500
Sweetgum	1	23400	21300	--
	2	32700	23400	13400
Southern red oak	1	45500	10700	8600
	2	36500	7400	5900
Southern white oak	1	52000	6900	4700
	2	41000	9700	5500
Black tupelo	1	39000	9400	--
	2	41300	15700	--
Sycamore	1	43300	9600	--
	2	30000	12100	--
Yellow-poplar	1	35800	11000	7400
	2	22800	8800	7500
White ash	1	47600	15500	7100
	2	50400	19500	8200
Red alder	1	36200	12900	4400
	2	17500	11500	5300
Northern black cottonwood	1	15100	20100	6700
	2	19400	19200	10900
Silver maple	1	18700	28800	9800
	2	36400	37100	17100
Pin oak	1	26000	7200	3600
	2	28000	6800	2600
Black oak	1	33200	6400	4400
	2	24800	7600	2600
Post oak	1	25600	7600	4800
	2	32800	6400	2700
Shagbark hickory	1	34800	24000	19200
	2	37200	24400	14800
American beech	1	42000	6400[b]	--
	2	29200	7600[b]	--

[a]Values based upon 4-6 determinations. Dashes indicate bark was unable to be tested for various reasons.
[b]Test done on total bark.

TABLE XL

MODULUS OF ELASTICITY VALUES[a]
SOFTWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
White spruce	1	20600	--	12200
	2	29600	--	17300
Jack pine	1	25700	--	4400
	2	24600	--	3800
Loblolly pine	1	25200	6700	3800
	2	21200	6500	2100
Western hemlock	1	43300	12600	7000
	2	34900	13200	4400
Douglas-fir	1	42400	28200	--
	2	43100	21700	1000
Slash pine	1	33100	3400	1900
	2	29800	3300	1900
Balsam fir	1	35200	6200	--
	2	21600	7000	--
Engelmann spruce	1	21600	24500	--
	2	30000	25500	6700
Ponderosa pine	1	15200	6500	2000
	2	34800	5100	3700
Lodgepole pine	1	30100	6700	1900
	2	24700	25900	5300
Western larch	1	40900	10900	5300
	2	40800	31600	8100
Red pine	1	18600	25800	1800
	2	20000	28900	3100
Shortleaf pine	1	35900	14300	3100
	2	41800	25000	3800
Virginia pine	1	48100	37100	3700
	2	23000	30700	7800
Longleaf pine	1	49500	33900	3800
	2	42000	26200	5900
Black spruce	1	31400	30900	7000
	2	25100	25000	5900

[a]Values based upon 4-6 determinations except the outer bark for western hemlock tree #2 which is one determination. Dashes indicate bark was unable to be tested for various reasons.